AN INVESTIGATION OF THE DURABILITY OF UK GROWN SOFTWOOD DISTRIBUTION POLES CCA-TREATED BY SAP-DISPLACEMENT.

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This thesis is presented to the Council for National and Academic Awards in partial fulfilment of the requirements for the award of the degree of Doctor of Philosophy.

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AN INVESTIGATION OF THE DURABILITY OF UK GROWN SOFTWOOD DISTRIBUTION POLES CCA-TREATED BY SAP-DISPLACEMENT.

Sandra D. Hainey B.Sc. (Hons)

ABSTRACT.

The decay susceptibility of UK grown Corsican pine, Scots pine, Norway spruce and Sitka spruce poles treated with CCA by the high pressure sap-displacement process, was investigated using full size poles in a field site and representative pole sections in an accelerated decay system.

Analysis of cores removed from the field poles showed a significant difference in the treatability of the four wood species. While satisfactory uptake and penetration of copper, chromium and arsenic were recorded for Corsican and Scots pine and Norway spruce, significantly lower levels of CCA penetration and retention were found in Sitka spruce poles. The narrow preservative penetration and extensive checking recorded in Sitka spruce poles contributed to the isolation of decay fungi after only four years field exposure.

Radial distribution of the three preservative elements showed a gradient of chromium and arsenic which generally decreased from pole surface to centre, however, in all species except Sitka spruce an intermediate peak in copper concentration was recorded. Analysis of core samples removed annually from the groundline region of field poles indicated that migration of the CCA salts had occurred. This migration appeared to be complete after the first year of field exposure. Significant increase in copper and chromium levels in soil adjacent to poles of each species, indicated that leaching of the CCA components had occurred from the poles to surrounding soil. This small leaching effect is not expected to have a significant adverse effect on protection of the poles or to act as a soil pollution hazard.

Exposure of pole sections to the natural soil microflora in the accelerated decay system resulted in untreated control sections suffering extensive soft rot decay of their curved and checked surfaces. Soft rot attack of CCA-treated sections was however, limited to small surface pockets at the untreated or poorly treated regions of their checked surfaces.

Inoculation of the pole sections with basidiomycete fungi produced major differences in the type and location of decay development between the untreated and CCA-treated samples. Despite the presence of a heavy basidiomycete inoculum, decay of untreated control sections continued to be due to soft rot attack of curved and internal checked surfaces. Severity of decay was in the order of Corsican pine > Scots pine > Norway spruce > Sitka spruce. Decay of CCA-treated sections however, was produced principally by internal basidiomycete attack with large internal pockets of brown rot decay in the Sitka spruce sections. Severity of decay was the reverse of that for untreated pole sections i.e. Sitka spruce > Norway spruce > Scots pine > Corsican pine. The unexpected patterns of decay in CCA-treated pole sections was linked to the presence of CCA in the wood and soil, and the significantly lower moisture levels present in these sections.

The validity of using the accelerated decay system to assess the performance of the four treated wood species is discussed.

CONTENTS

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ABBREVIATIONS.

m	metre
nm	nanometre
mm	millimetre
ml	millilitre
g	gramme
ug	microgramme
mg	milligramme
kg	kilogramme
umol	micromole
M	molar
^{o}	degree
^{o}C	degree centigrade
%	percent
rpm	revs per minute
min	minute
ppm	parts per million
w/w	weight to weight
w/v	weight to volume
Cu	copper
Cr	chromium
As	arsenic
AAS	atomic absorption spectrophotometry
CCA	copper chrome arsenic
ESI	Electricity Supply Industry
GL	groundline
HPSD	high pressure sap-displacement
PAGE	polyacrylamide gel electrophoresis
PVC	polyvinyl chloride
SDS	sodium dodecyl sulphate
TTC	triphenyltetrazolium chloride
TTF	triphenyltetrazolium formazan
WHC	water holding capacity
UK	United Kingdom
ul	microlitre

CHAPTER 1

INTRODUCTION

1. INTRODUCTION.

1.1. The UK Softwood Resource.

Wood has long been regarded as an important natural, renewable resource which may be easily worked and used for a variety of purposes, e.g. building timbers, joinery, poles, fencing, furniture and pulp. Consequently, the world forests must be carefully managed to control deforestation, to ensure that a continued supply of this valuable material is always available. In the UK there are about 2 million hectares of broadleaf and coniferous forests, half of which are reportedly owned by the Forestry Commission and the Department of Agriculture, Northern Ireland (CAS, 1980). These state forests are almost all productive and are therefore intensely managed for timber production (CAS, 1980).

Within the UK forests, softwood species are dominant, 85% of the land held by the Forestry Commission being covered by a variety of conifers. The most commonly planted species is Sitka spruce (*Picea sitchensis* (Bong) Carr), followed closely by Norway spruce (*Picea abies* L. Karst), both of which accounted for a combined production of almost 2 million cubic metres in 1984 (Harding, 1988). Total pine production was recorded at about 1.2 million cubic metres during the same period and consisted largely of Scots pine (*Pinus sylvestris* L.), Corsican pine (*Pinus nigra* var *maritima* Ait) and Lodgepole pine (*Pinus contorta* Dougl.).

The commercial and economic importance of softwoods was emphasised by Harding (1988), stating that they account for about

90% of all timber used in Britain, however the majority of this wood is imported from a number of countries, including those in Scandinavia, North America and parts of Northern and Eastern Europe. Gradually however, due to improved forest management, British softwoods are more readily available and are claiming an increasing share of the home market. In addition, the British grown conifers have an advantage over imported material in that they grow more vigorously and at maturity (40-50 years old) are of comparable size to the more slowly grown timber imported from Scandinavia (Harding, 1988).

The Electricity Supply Industry (ESI) in the UK have shown an increasing interest in the availability of such home grown material for use as distribution poles. Although it is known that there are sufficient trees of suitable size and strength available from home grown supplies (Fowlie and Sheard, 1983), the majority of softwood poles are still imported from Scandinavia, in particular Finland (Aaron and Oakley, 1985). The principal softwood species used for poles is Scots pine, however, it is possible that UK grown spruces and other pines may be used for this purpose. The ESI and the Forestry Commission have realised the economic importance of using the home grown supply and carried out a joint research project to investigate the possible use of UK softwoods for overhead power line supports (Fowlie, 1981).

A pre-requisite to the use of these home grown timber species is that the material must be satisfactorily treated for protection against microbial decay. The treated timber must then be thoroughly tested to determine its performance and long term

durability. Problems exist however, in the treatment of spruce species, such as Sitka spruce, which are resistant to impregnation and difficult to treat satisfactorily by conventional pressure impregnation processes (Smith and Cockcroft, 1961).

1.2. Softwood Structure.

Although softwoods contain several different cell types, over 90% of the total cell volume consists of the vertically oriented fibre or tracheid. Tracheids are hollow, needle-shaped units, generally 2.5-5.0 mm in length and packed closely together to give a honeycombed effect on cross-section. In the tree, tracheids perform two major functions, namely support and conduction of liquids (sap). Strength is conferred to the wood by thick-walled tracheids with small cavities formed near the end of the growing season i.e. summerwood, whilst sap is conducted by thin-walled tracheids with large cavities formed early in the growing season i.e. springwood. The formation of these two types of cells produces concentric growth or annual rings on cross-section of the wood.

Small openings, called pits, are present in fibre walls, particularly in springwood, and are matched in adjoining fibres to form pit-pairs which allow the flow of liquids through the wood. Longitudinal tracheids are also connected to the radially oriented wood rays by means of pits, thus enabling radial movement through wood. Pits existing between vertical tracheids and ray parenchyma or ray tracheids are referred to as

cross-field pits.

The wood cell wall consists primarily of three polymeric materials, namely cellulose, hemicellulose and lignin which constitute 95-98% of the total cell wall (Thomas, 1977). Cellulose, in its crystalline form, is arranged into bundles called microfibrils and these are embedded in a matrix of hemicellulose and lignin, an amorphous non-polysaccharide material. Variations in the arrangement of the microfibrils results in the wall being composed of a number of distinct layers, as can be seen in Figure 1.1.

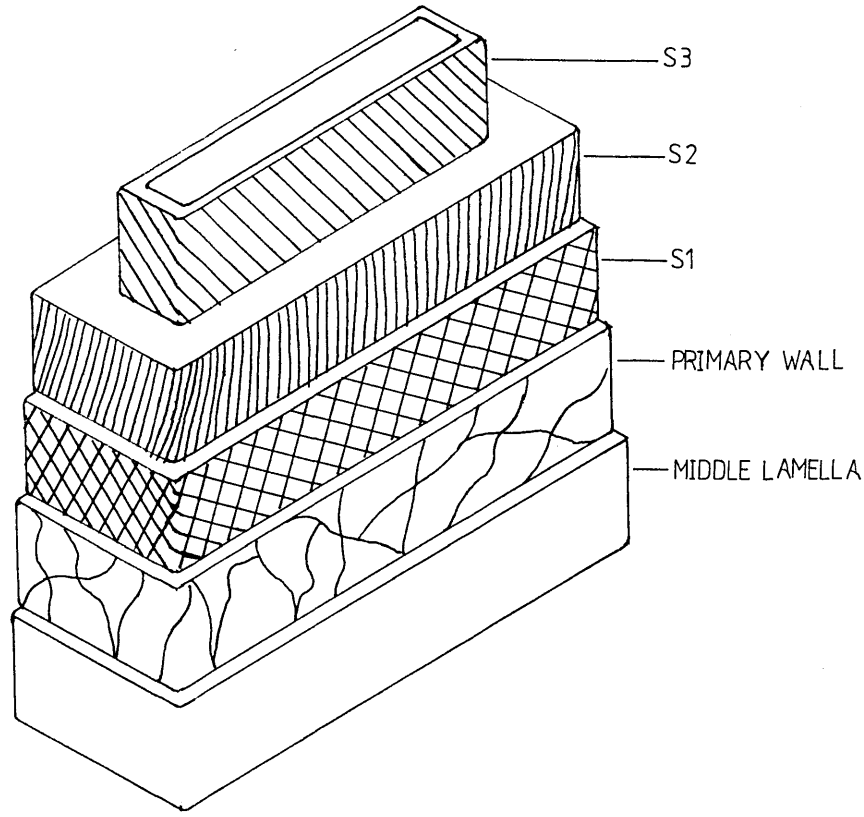


Figure 1.1. Simplified structure of the wood cell wall.

The outermost, or primary wall, is a very thin layer characterised by a random arrangement of the cellulose microfibrils. Adjacent to this layer is the secondary wall which is subdivided into three distinct regions, namely the S1, S2 and S3 layers. The middle layer (S2) comprises about 85% of the total wall volume and possesses microfibrils lying parallel to each other at an angle of 10-30^{0} to the vertical (Desch and Dinwoodie, 1981). Individual tracheids are bound together by a substance composed of about 80% lignin, forming a region referred to as the middle lamella. Binding together of the fibres results in the formation of the gross structure of wood.

In softwoods and hardwoods alike, there are two main types of wood, forming a central core of heartwood surrounded by an outer ring of sapwood. Histologically, the sapwood and heartwood are identical, the heartwood being formed by the gradual conversion of dying sapwood. During this transformation, many chemical changes take place resulting in the generation of a large amount of extractives. In particular, pine wood is known to synthesise specific fungicides and phenolic compounds (Sjostrom, 1981) which have been reported to confer some degree of natural durability on the heartwood of Scots pine (Purslow, 1976; Gray, 1990).

A major difference between sapwood and heartwood is in their moisture content and permeability to liquids. Both properties are much reduced in heartwood material due to blockage, or aspiration of the fibre pits. Specialised membranes exist between pit pairs with a central thickening, or torus, which is attached to the periphery of the pit cavity by fine fibrous strands (Figure 1.2).

Aspiration of these pits results from the membranes being drawn to one side and bonding to the fibre wall (Figure 1.2), consequently liquids can no longer pass between the fibres. The drying of wood prior to preservative treatment may also cause pit aspiration within the sapwood region with subsequent difficulties in the penetration of liquids through the wood (Thomas, 1977). This reduction in permeability is therefore of major importance in the preservative treatment of timber, particularly poles.

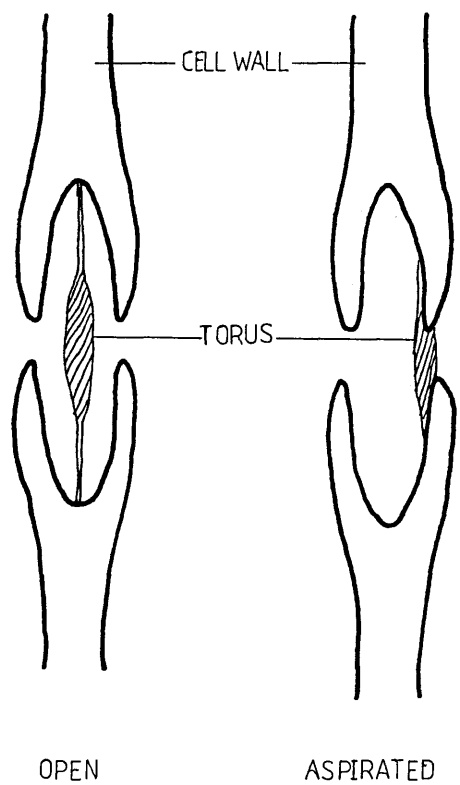


Figure 1.2. Diagram of open and aspirated bordered pit pairs.

1.3. Treatment of Poles and their Decay.

Timbers in contact with the ground, as in the case of distribution poles, have long been known to be highly susceptible to decay by micro-organisms. Decay is enhanced by the soil in which it is embedded, since it provides more or less permanently damp conditions and acts as a constant source of infection. Such potential for decay is however, appreciated and timbers used in this situation are treated with a suitable preservative.

1.3.1. Treatment with Creosote.

It is estimated that in the UK, the ESI have approximately 6 million poles in use, of which the majority are impregnated with creosote (Bruce and King, 1986).

Creosote is produced by the distillation of coal tar and contains a wide spectrum of chemical constituents, including hydrocarbons, phenols and tar bases, which enable it to control the growth of a range of different micro-organisms. Treatment of poles with creosote requires them to be dried to below 28% moisture content, and for the preservative to be applied under pressure to obtain full sapwood penetration, as stipulated in the current British Standard (B.S. 144: Part 2, 1990). Full penetration of the heartwood is impossible and a region at the centre of the poles always remains untreated. Heartwood is difficult to treat due to a number of structural reasons, including the high degree of pit aspiration. Additionally, inadequate treatment of some poles may occur due to insufficient

drying prior to impregnation, resulting in poor creosote penetration and leaving an annulus of untreated sapwood (Morris and Calver, 1985).

Failure of creosote-treated poles generally occurs when decay fungi gain access to the untreated centre via checks which extend through the full depth of creosote treatment. Internal cavities of decay are produced, with consequent strength losses to the pole. Such internal decay is produced by the basidiomycete fungi, which may be classified into one of two groups depending on their ability to utilise the lignin present in wood cell walls. The white rot fungi are capable of degrading both the carbohydrate and lignin components of wood cell walls, producing erosion troughs which initiate at the lumen wall, extend through the lignin-rich S3 layer and into subsequent wall layers (Liese, 1970; Wilcox, 1970; Levy and Dickinson, 1981).

Decay by brown rot fungi, as reviewed by Highley (1987), results from rapid depolymerisation and utilisation of the cellulose and hemicellulose components of the cell wall. Although lignin is modified by these fungi, it remains relatively undigested. Attack by brown rot fungi is initiated by hyphae growing in the cell lumen and in contact with the S3 layer (Liese, 1970; Wilcox, 1970), however, there appears to be diffusion of the degrading enzymes through the S3 layer to the cellulose-rich S2 layer where extensive degradation occurs (Highley, 1987).

Brown rot decay is reported to be the major decay hazard in creosote-treated softwood poles in the UK, in particular, by the fungus *Lentinus lepideus* Fr. (Bruce, 1983). This organism is well

documented as being the major decay producer in creosoted timber (Cartwright and Findlay, 1958).

1.3.2. Treatment with Copper, Chrome, Arsenic (CCA).

An alternative to the use of creosote for the treatment of poles is the water-borne preservative, copper, chrome arsenic (CCA). CCA was first introduced by the ESI in the UK when "bleeding" of creosote from treated poles became a hazard to pole handlers and caused labour relationship problems. Although the cost of production is the same as creosoted poles, it is still estimated that less than 5% of the poles in service in the UK are CCA-treated (Fowlie, pers. comm. 1989).

CCA formulations used in the treatment of poles consist of a mixture of copper sulphate, sodium or potassium dichromate and arsenic pentoxide (B.S. 4072: Part 1, 1987) and are applied to poles, previously air-dried to under 30% moisture content, by a full cell vacuum and pressure process, according to B.S. 4072: Part 2 (1987). On contact with the wood, a series of complexes are formed with the copper, chromium and arsenic which become insoluble during a post-treatment drying/fixation period. The resultant CCA complexes are distributed both through the wood cell wall and on the lumen surface (Chou et al., 1973). While copper and arsenic impart a toxic effect to fungi and insects, the chromium content plays an important role in the fixation and permanence of the preservative, but apparently has little effect on its toxicity (Wallace, 1968).

Aaron and Oakley (1985) reported that CCA-treated poles have given satifactory service over a number of years. In addition, a study in 1957 (Anon, 1957) of poles exposed to severe biological hazards over twenty one years, showed that CCA prevented premature pole failure. Decay of poles treated by CCA does however occur as reported by Friis-Hansen and Lundstrom (1989), when soft rot of the outer and inner sapwood was discovered in a number of poles exposed for 10-20 years in a range of environmental conditions.

Savory (1954) first introduced the term 'soft rot' to describe the decay produced by some ascomycetes and deuteromycetes which causes a gradual softening of the wood surface. Soft rot fungi primarily degrade the wood carbohydrates and are capable of producing two distinct decay types; (i) formation of erosion troughs extending from the lumen wall outwards, similar to white rot decay, (ii) cavity formation around hyphae growing within the S2 layer (Nilsson, 1988). Of the two decay types, cavity formation tends to be more characteristic of soft rot. Cavities are produced by dissolution of the cell wall carbohydrates following alignment of the fungal hyphae along the angled microfibrils of the S2 layer and are therefore typically produced parallel to the microfibrils with pointed or conical ends (Nilsson, 1976). Soft rot cavity formation has also been shown to result from 'start-stop' oscillatory growth of hyphae and subsequent cavity widening around these hyphae (Leightley and Eaton, 1977; Hale and Eaton, 1985). This form of hyphal growth, and subsequent dissolution of the wood cell wall therefore leads to the formation of chains of discrete cavities.

The treatment of poles by either creosote or water-borne preservatives specifies that the sapwood must be fully penetrated by the preservative (B.S. 1990, 1984). In most wood species this is readily achieved, however, there are a few species, in particular the spruces, where it is virtually impossible to achieve full sapwood penetration (Aaron and Oakley, 1985).

1.4. Preservative Treatment of Refractory Species.

Fowlie (1981) reported that spruce wood poles have not been used in the UK as overhead line supports due to their resistance to impregnation with preservatives. Over the years there have been numerous investigations into the reasons for this refractory behaviour, many of which were reviewed by Liese and Bauch (1967). They reported that several anatomical factors were responsible, including increased levels of pit aspiration, particularly during air-drying of the wood. However, the main reason was thought to be the low permeability of the ray cells resulting from the small proportion of ray tracheids, which are regarded as the main radial pathway for penetration of liquids. Pits existing between ray parenchyma and longitudinal tracheids (cross-field pitting) were also found to be smaller than those of the more permeable wood species, such as pine (Baines et al., 1983).

Several investigations have been undertaken in recent years to improve the permeability of refractory species to preservatives and to determine the associated structural changes in the wood. One approach has been to examine the effect of ponding of poles, which involves the immersion or spraying of

timber with water, to determine the effects of naturally occurring bacteria on the wood (Dunleavy and Fogarty, 1971; Unligil, 1972; Fogarty, 1973). Commercial treatment trials were undertaken by Dunleavy and McQuire (1970) on full sized transmission poles stored in water for up to twelve months, and subsequent treatment with preservatives showed greatly increased permeability of Sitka and Norway spruce poles. Microscopical examination of the ponded wood indicated that the torus and pit membranes had been destroyed, resulting in enhanced permeability. A further study by Fowlie and Sheard (1983) showed similar results following the ponding of Sitka and Norway spruce poles, however, the total processing time of 20 months was regarded as unacceptable on a commercial basis. Since the increased permeability of ponded wood was due to the enzymatic action of micro-organisms, Nicholas and Thomas (1968a) decided to investigate the direct application of such enzymes to wood. Improvement in the permeability of Loblolly pine was observed, resulting from the degradation of pit membranes by pectinase.

In addition to these biological methods of pre-treatment, the effect of incising (Best and Martin, 1969; Goodell et al., 1991), steaming (Nicholas and Thomas; 1968b) and ozone-treatment (Lantican et al., 1965) have all been examined and reported to enhance wood permeability. An alternative approach has been to improve the penetrating properties of the carrier liquid, as reported by Rak and Clarke (1975) who utilised concentrated aqueous ammonia solutions for this purpose.

Alternatively, a different treatment process may be used, such as sap-displacement, which has been reported to give a

deeper, more even impregnation of the preservative than is obtained with conventional pressure processes (Gersonde, 1968). It is therefore possible that this process may give improved preservative treatment of home grown timber species, including spruces.

1.5. Sap-Displacement Processes.

Sap-displacement processes involve the replacement of sap of freshly felled timber by preservative formulations, such as copper, chrome arsenic. The method was first introduced by Boucherie in 1838 and involved the introduction of preservative solutions into the existing sap-stream of standing or freshly felled trees (Wilkinson, 1979). The process was very slow, taking fifteen days to treat a 30 foot pole (Hudson, 1968), consequently numerous studies were undertaken to improve the efficiency of the process.

Modifications have included the fitting of caps to individual poles through which the chemicals are passed, and application of pressure and suction to enhance the movement of liquids through the timber. The introduction of the pressure and suction method by Gewecke allowed a reduction in treatment times to 20-30 hours (Wilkinson, 1979). This process, as operated today, is used in a number of treatment plants in Denmark to treat spruce poles, in fact, 95% of all Norway spruce transmission poles in Denmark are treated by sap-displacement using a vacuum or vacuum/pressure process (Shorland and Mason, 1974). As a consequence of these successful reports, a modified CCA-treatment plant was installed in the UK by Messrs. Calders

and Grandidge (Grangecourt depot, Gloucester) to operate a pressurised sap-displacement process (Fowlie and Sheard, 1983).

The treatment process is carried out in a conventional pressure cylinder where the poles are completely immersed in the CCA preservative under a pressure of about 10 bar. Simultaneously, a vacuum of 1 bar is applied to one end of the poles by means of individual metal sap-displacement caps. These conditions are maintained for 40 hours with the extracted sap solution being continually re-circulated with the preservative (Fowlie and Sheard, 1983). Figure 1.3 shows a schematic diagram of the pressure cylinder used during the process.

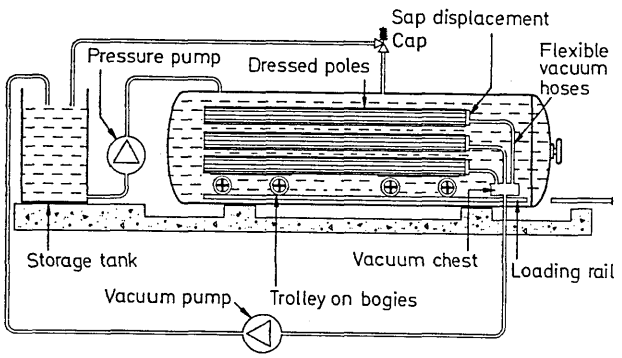


Figure 1.3. Schematic diagram of the pressure cylinder used in the high pressure sap-displacement process (from Evans et al., 1991)

Preliminary studies by Fowlie and Sheard (1983) on the treatment of UK grown spruce poles by a pressurised sap-displacement process have indicated that satisfactory levels of CCA loading and depth of penetration can be achieved with Norway spruce, but the success of the treatment of Sitka spruce poles was dependent on the width of sapwood in the growing tree. Fowlie and Sheard (1983) also reported an additional advantage of the sap-displacement process in the treatment of UK grown Corsican pine poles. Since treatment is carried out immediately after felling, there is no need for extended drying periods that are required prior to traditional pressure impregnation processes. Sap-displacement therefore precludes post-harvest deterioration by decay fungi, particularly in the case of Corsican pine which dries slowly and is consequently more susceptible to decay (Aaron and Oakley, 1985). The value of eliminating this drying period is illustrated by the reported incidences of pre-treatment infection of wood poles during normal seasoning periods (Morrell et al., 1987; Zahora and Dickinson, 1989).

Although it is evident that sap-displacement of poles will contribute to the eradication of pre-treatment decay, there exists little or no information on the performance of such treated timber whilst in service. A detailed testing procedure is therefore a necessary pre-requisite to widespread utilisation of these products.

1.6. Performance Testing of Treated Poles.

Prior to the introduction of any new wood preservative or method of treatment, thorough testing of the performance of the treated product must be undertaken. The success of the treatment depends on a number of factors, namely the penetration, permanence and distribution of the chemicals within the wood and the subsequent protection of the wood against microbial degradation. A variety of methods exist for the testing of treated poles, ranging from field testing of full size poles to accelerated laboratory testing of small woodblocks and stakes.

1.6.1. Field Testing.

The most accurate means of testing treated timber is to expose it under natural, field conditions and periodically assess its performance to determine an average service life. In the case of salt-treated poles, a number of investigations have been undertaken to examine their performance whilst in service (Anon., 1957; Friis-Hansen, 1977; Leightley, 1986; Friis-Hansen and Lundstrom, 1989). The majority of these studies involved determinations of the extent of decay, particularly by soft rot organisms, with limited data reported on the preservative levels within the wood and their permanence on exposure to field conditions. Belford (1970) reported a lack of field studies of the permanence of salt-type preservatives and few authors have reported on this subject since then.

Field testing of treated timber may require twenty or more years of exposure to give satisfactory results (Johnson et al., 1982) and may therefore greatly delay the development of new formulations or treatment processes. Consequently, a variety of accelerated tests have been introduced as part of the initial screening of new preservative products.

1.6.2. Accelerated Testing.

1.6.2.1. Laboratory Tests.

Laboratory tests using small woodblocks e.g. 20 x 20 x 20mm, have been well documented for the examination of several aspects of preservative treatments, e.g. preservative permanence (Rak and Clarke, 1974; Norton, 1979), micro-distribution of preservative components (Drysdale et al., 1980; Hedley et al., 1990), and decay susceptibility of the treated timber (Da Costa and Osborne, 1968; Gray and Dickinson, 1987; Green et al., 1989)

Although these tests give rapid results and are considered suitable for establishing relative performances of preservatives (Anon., 1978), they are of limited use in the prediction of field performance. The size, orientation and treatment of small blocks often bear little resemblance to the full size commercial products of interest, thus interpretation of results must be handled carefully.

Problems associated with the use of field and laboratory testing systems, briefly mentioned above, have in recent years resulted in the development of soil-bed test systems ("fungal

cellars"), in an attempt to bridge the gap between the two test methodologies.

1.6.2.2. Soil-Bed Test Systems.

In soil-bed tests, as in most laboratory soil burial test systems, wood specimens are exposed to conditions favourable to rapid microbial decay. An increasing number of these systems are being developed, particularly for examining the decay susceptibility of treated timber using small preservative treated stakes (Hedley, 1983; Clubbe, 1983; Vinden et al., 1983a & b). However, it is possible that much larger samples may be tested which are a closer representation of the full size commercial product.

An important consideration which is not examined in most accelerated test systems, is the partially preserved nature of the timber in poles. The combination of an outer treated band surrounding a central core of untreated wood will obviously determine the performance of the material under natural conditions and is not examined using other laboratory tests or treated stake tests. In particular, the presence of checks extending into the untreated core would increase the decay hazard for these poles. Testing of wood specimens which incorporate these properties would therefore more closely represent conditions which the poles would encounter in the field.

1.7. Aims of Project.

As mentioned previously, the Electricity Supply Industry and Forestry Commission in the UK jointly funded an investigation into the utilisation of home grown spruce poles as overhead line supports (Fowlie, 1981; Fowlie and Sheard, 1983). Problems do however, exist in the preservative treatment of such poles due to their natural resistance to impregnation. This is emphasised in B.S. 1990: Part 1 (1984) where it is stated that Norway and Sitka spruce cannot be treated by the conventional procedures described in B.S. 913 (1973) and B.S. 4072 (1987). It is therefore specified that these species should be treated to meet the requirements of full sapwood penetration and net retention using a suitably modified version of one of the above procedures. As a consequence, Fowlie and Sheard (1983) initiated an investigation of the CCA treatment of spruce poles by pressurised sap-displacement.

The preliminary studies resulted in the ESI accepting, in principle, the use of home grown spruce poles treated by pressurised sap-displacement. Messrs. Calders and Grandidge Ltd. (Grangecourt Depot, Gloucester) offered to supply sap-displacement treated spruce poles commercially at a cost comparable to imported Scots pine poles treated by conventional methods. However, doubts on the long term durability of these poles caused individual rea oards to be reluctant to use them (Fowlie, pers. comm., 1989).

Although results from the initial study (Fowlie and Sheard, 1983) were limited, it was suggested that a viable product may be

achieved with Norway spruce poles, and Corsican pine, which is readily available in the UK, was also shown to give excellent loading and penetration of CCA. It was therefore obvious that the use of pressurised sap-displacement merited further examination, consequently this project was funded by the Electricity Council Research Centre to investigate the long term performance of these commercially treated home grown poles. In addition to the three species mentioned above, Scots pine poles are also included in the study due to their ready availability in the UK, and their current widespread utilisation by the ESI.

The main aims of the research are threefold:-

(1) To establish for the ESI, the suitability of Corsican pine, Scots pine, Norway spruce and Sitka spruce for use as distribution poles after CCA-treatment by high pressure sap-displacement. This will be established by :

(a) examination of the treatability of the four species by comparing the penetration, retention and distribution of CCA components in samples removed from commercially treated poles. Monitoring of the permanence of copper, chromium and arsenic by chemical analysis of wood and soil after field exposure of the poles will be undertaken to determine the efficacy and environmental acceptability of the treated product;

(b) development of an accelerated decay system to provide optimum conditions for decay susceptibility testing of the four treated species. The system will be designed to expose wood specimens to the natural soil microflora and to artificially

introduced basidiomycete decay fungi, thereby incorporating the full range of fungal decay hazards encountered in the field situation. Examination of the field exposed poles for decay development will also be undertaken;

(c) monitoring the extent of check formation in full size poles of the four wood species exposed to field conditions, and determining the importance of these checks in decay development under field and accelerated decay conditions.

(2) To develop appropriate testing methods for the examination of the types and location of decay in untreated and CCA-treated pole sections during exposure to accelerated decay conditions. The effects of CCA presence, checking and moisture on patterns of decay development under these conditions will also be examined.

(3) To assess the validity and value of using an accelerated decay system as a method of evaluating the performance of treated pole sections of the four wood species. This will involve comparative appraisal of data obtained from both the field and accelerated decay systems, and assessment of the effects of the different physical conditions on performance of pole sections of each of the four wood species.

CHAPTER 2

EXPOSURE OF POLES TO FIELD CONDITIONS

2.1. INTRODUCTION.

Specifications for the treatment of softwood poles in the UK, state that full sapwood penetration by the preservative (creosote or CCA) must be achieved (B.S. 1990: Part 1, 1984). Treatment of spruce poles by conventional impregnation processes with creosote (B.S. 144, 1990) or CCA (B.S. 4072, 1987) however, does not result in adequate penetration of the preservative. Consequently, it is specified (B.S. 1990: Part 1, 1984) that poles of Norway and Sitka spruce should be preserved using a suitable modification of one of the conventional treatment processes in order to satisfy the requirements of full sapwood penetration. Recent research (Fowlie, 1981; Fowlie and Sheard, 1983) has investigated whether this problem of poor preservative penetration can be resolved by treatment of the poles with CCA using a high pressure sap-displacement process. As part of this present study, the performance of such poles when exposed to field conditions was examined.

The performance of CCA-treated poles under field conditions will depend largely on the type of wood species involved, initial levels of the preservative and the depth of penetration achieved. For long-term success, however, the preservative must remain firmly fixed within the wood with limited leaching to the surrounding environment.

Fixation of chromium based wood preservatives, such as CCA, has been described by Christensen (1990) as an "abstract and non-defined process". The detailed series of reactions which are thought to occur during this process were reported in a series of

papers (Dahlgren, 1972, 1974, 1975a and b ; Dahlgren and Hartford, 1972a, b and c; Pizzi, 1981, 1982a, b and c) and were reviewed by Plackett in 1983. During fixation reactions, hexavalent chromium is converted to its trivalent form (causing the characteristic green colour of CCA-treated wood), which is then associated with the fixation of all three preservative components in the wood by the formation of insoluble complexes.

Previous work on the permanence of CCA within treated wood has been mainly undertaken on small wood specimens in laboratory-scale experiments, and has shown CCA to be highly resistant to leaching (Henshaw, 1979; Plackett, 1984). Some leach losses of the preservative have however, been recorded, with very small losses of chromium (Dunbar, 1962; Fahlstrom et al., 1967; Evans, 1978) and proportionally greater losses of copper and arsenic.

Research on factors affecting leaching of various preservatives, including CCA, were reviewed by Cockcroft and Laidlaw (1978) and were found to include permeability of the wood, type of impregnation process, sample size, moisture content of the wood, chemical composition of the preservative and the temperature, pH and ionic content of the leach water. These authors emphasised the lack of information on field trials and referred to the problems in using laboratory leaching methods to predict the behaviour of treated material under service conditions. This problem was also reviewed by Wallace (1964), who stated that certain preservatives which were shown to be appreciably leachable in the laboratory were later shown to give surprisingly good performance in field tests and in service.

Although the levels, penetration and permanence of CCA components within field exposed poles are important factors in the prevention of microbial decay, a number of other factors also affect the decay susceptibility of such poles. In particular, checking may cause a major problem in poles which have been treated by sap-displacement. Checking of timber is well known as a problem encountered during the drying of wood (Schneiwind, 1963; Mackay, 1973) and occurs during the post-treatment drying period which is required after sap-displacement with CCA. The presence of these checks may provide a route of entry for decay fungi to the untreated core of the poles thereby increasing the likelihood of internal decay. Low preservative penetration, which is often observed in impermeable species such as spruce and Douglas fir (Liese and Bauch, 1967) would probably increase this problem since untreated regions will be more readily accessible. A number of studies employing various strategies have been undertaken in an attempt to reduce the extent of checking in poles, including kerfing (Ruddick, 1988; Morrell, 1990) and the addition of polyethylene glycol (PEG) as part of the pole treatment system (Trumble and Messina, 1986).

The moisture content of wood also has a significant effect on its suceptibility to microbial decay, and on the type of decay which may occur. Decay fungi can only cause serious decay of wood when the moisture content is greater than fibre saturation point Fibre saturation point is around 30% moisture content of most wood species (Levy and Dickinson, 1981), and is the point at which no 'free' water (ie. water not bonded to the wood) is present and only 'bonded' water (i.e. water which is physically

or chemically bonded to the wood) remains. The moisture content of CCA-treated poles will have an important effect on durability of the timber, the extent and occurrence of checks and possibly the permanence of the preservative. However, investigations on small woodblocks have shown CCA-treated wood in soil contact to have lower moisture uptakes than untreated woodblocks (Murphy, 1982; Gray, 1986; Pizzi and Conradie, 1986; Briscoe, 1987; Green et al., 1989). Pizzi and Conradie (1986) suggested that this hydrophobic character of CCA may be linked with the increased durability observed in CCA-treated wood.

Nutrient availability within wood has been shown to be an important factor in its colonisation and subsequent decay and is often associated with the re-distribution of soluble nutrients to evaporative surfaces (King et al, 1974, 1981). The presence of these soluble nutrients has been shown to increase both the extent and initial rate of soft rot decay (King et al., 1974; Waite and King, 1979). In CCA-treated timber, high nitrogen content of the wood has also been shown to increase the copper tolerance of soft rot fungi (Henningson, 1976) thereby reducing the efficacy of copper based preservatives. Migration of these soluble nutrients to the surface of CCA-treated poles during pre-treatment drying periods may therefore decrease the preservative effectiveness (King et al., 1989), however, this problem may well be eliminated in sap-displaced poles since the timber is treated immediately after felling i.e. no seasoning period.

As detailed above, the durability of treated timber is dependant on a variety of factors. Few studies however, have

examined how these factors influence the field performance of finished wood products, and little is known of the durability of distribution poles treated with CCA by sap-displacement. The aim of the work presented in this chapter of the project was therefore to undertake a detailed investigation of the treatability and field performance of UK grown pine and spruce poles treated with CCA by the sap-displacement process. This was achieved by examining levels, penetration and distribution of CCA components within such poles, and by monitoring the permanence of these components over several years field exposure. Both the extent of checking and the moisture profiles in each of the four wood species were also investigated to evaluate their importance as factors affecting the microbial decay processes within the poles.

2.2 METHODS.

2.2.1. The Field Site.

For examination of the performance of commercially treated UK grown poles under service conditions, a field site was developed in 1984 at Tealing, near Dundee, Scotland (site provided by the North of Scotland Hydro-Electric Board). The site was set up prior to the start of this project and is briefly described by Evans et al (1990).

Five UK grown 10m poles of each of Corsican pine (*Pinus nigra* var *maritima* Ait), Scots pine (*Pinus sylvestris*. L.), Norway spruce (*Picea abies*. L. Karst) and Sitka spruce (*Picea sitchensis* (Bong) Carr) were commercially treated with a 1.8% CCA Type II solution (35% $CuSO_4.5H_2O$: 45% $Na_2Cr_2O_7.2H_2O$: 20% $As_2O_5.H_2O$; B.S. 4072: Part 1, 1987) at Calders and Grandidge, Grangecourt depot, Gloucester. The poles were impregnated by sap-displacement following the schedule described in section 1.5, and air-dried for four months to allow suitable time for fixation of preservative elements.

The twenty poles were erected at the field site in a modified Latin square pattern which ensured that each species was represented at least once in each of the four rows and five columns. Figure 2.1 shows a plan of the overall layout, indicating the positions of the five poles of each species. A photograph of the site is given in Figure 2.2.

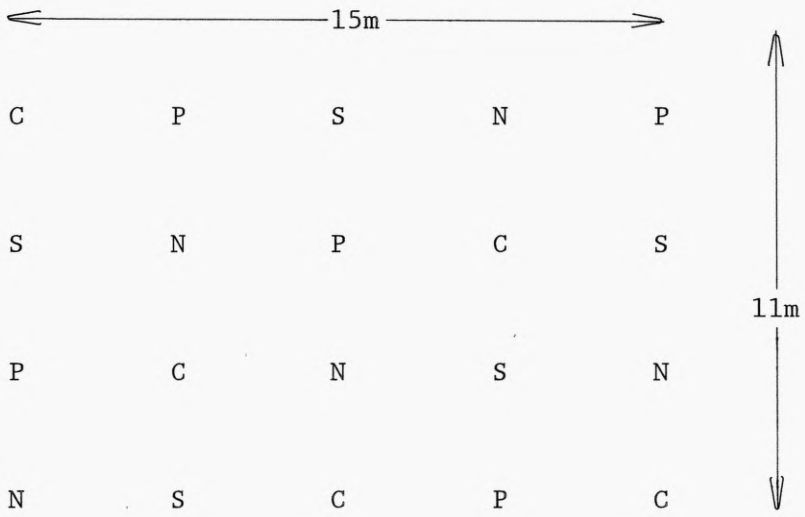


Figure 2.1. Position of Corsican pine (C), Scots pine (P), Norway spruce (N) and Sitka spruce (S) poles within the field site.

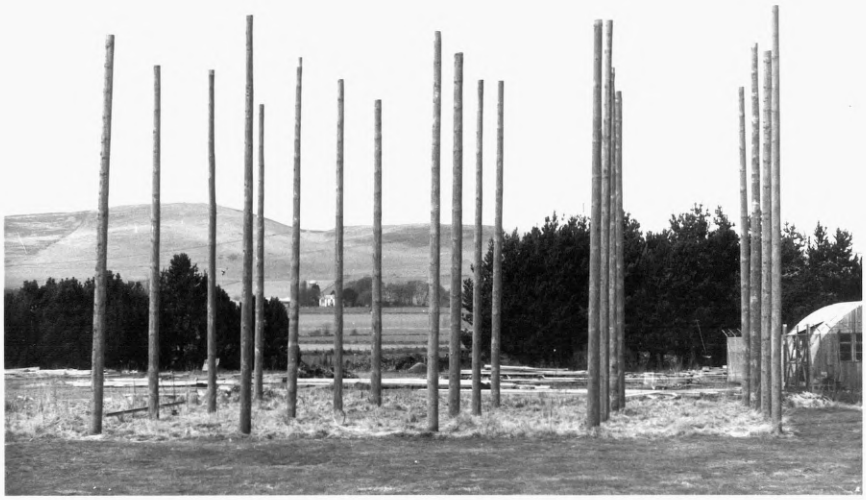


Figure 2.2. Photograph of the field site.

2.2.2. Determination of CCA Loading, Penetration, Distribution and Permanence.

2.2.2.1. Sampling of Poles.

Evans et al. (1987a) reported that immediately prior to erection, two poles of each species were randomly selected and six replicate core samples (4mm diameter) removed at an angle of 60° to the vertical at a position 1.5m from the butt end (corresponding to the groundline after implantation), for analysis of copper, chromium and arsenic levels before field exposure. Processing and analysis of the samples are described in Evans et.al.(1987a).

As part of this project, each of these twenty poles were sampled annually over a three year period of field exposure by removal of single cores (4mm diameter) from opposite sides of the poles at the groundline and at a height of 1m (80 cores per year). For ease of sampling, cores removed at the groundline were bored 60°to the vertical, whilst those at 1m were bored 90°to the vertical.

To establish radial distribution of the CCA elements, the cores were sectioned according to the plan in Figure 2.3 and each section analysed for its copper, chromium and arsenic content (as described in section 2.2.2.3). Sectioning of the cores was altered from the regime employed by Evans et.al.(1987a) prior to pole implantation in order to obtain a more detailed representation of CCA penetration and distribution than had previously been achieved. In the case of Corsican pine, where

very high CCA levels and deep penetration were observed, it was decided to analyse alternate 10mm portions of each core.

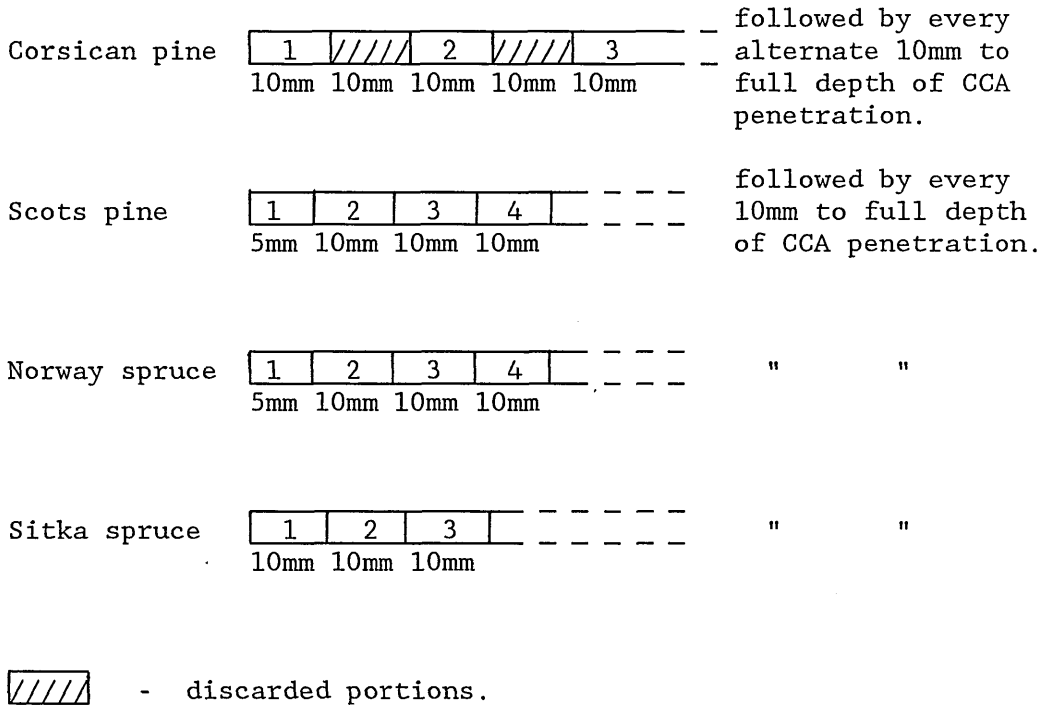


Figure 2.3. Diagram showing the different sectioning procedures for cores removed from poles of the four wood species.

2.2.2.2. CCA Extraction Procedure.

The preservative was leached from the wood and quantitatively analysed using the atomic absorption spectrophotometric method described in B.S. 5666: Part 3 (1979).

Each wood sample was finely divided using a scalpel, dried at 103±2°C and the dry weight determined. The weighed sample was transferred to a 25ml conical flask containing 5ml sulphuric acid (2.5M) and 1ml hydrogen peroxide (100 volumes) and heated to 75°C

for 30 minutes, the flask contents being mixed by occasional swirling. After heating, 10ml distilled water and 2.5ml sodium sulphate solution (3% w/v) were added and the material filtered through a Whatman No.1 filter paper into a 25ml volumetric flask. The wood was washed several times with distilled water and the final solution adjusted to 25ml with distilled water and mixed thoroughly.

2.2.2.3. Analysis of Metals.

The copper, chromium and arsenic content of the solutions were determined by atomic absorption spectrophotometry (Williams, 1972) and comparison with calibration curves produced from a standard solution containing the three metals. For this standard curve, five calibration solutions were prepared, containing 1,2,3,4 or 5ug/ml of chromium and 2,4,6,8 or 10ug/ml of copper and arsenic, in a solution of sulphuric acid (0.5M)/sodium sulphate (0.3% w/v).

The metals were analysed on a Perkin Elmer 372 atomic absorption spectrophotometer (AAS) with hollow cathode lamps and using the operating conditions shown in Table 2.1.

Table 2.1. Operating conditions of atomic absorption spectrophotometer for analysis of preservative elements.

Element	Wavelength(nm)	Fuel	Oxidant	Type of flame
Copper	324.8	Acetylene	Air	Oxidising, lean, blue
Chromium	357.9	Acetylene	Air	Reducing, yellow
Arsenic	193.7	Hydrogen	Argon	Colourless

Prior to carrying out any measurements, the sensitivity of the machine was maximised for each element by checking the absorbance of three standard solutions, containing 5ug/ml copper, 2ug/ml chromium and 40ug/ml arsenic, respectively. After setting the machine to zero absorbance with distilled water, absorbance readings for the above individual standards were maximised to values of 0.250, 0.100 and 0.400 for copper, chromium and arsenic, respectively and were maintained at or above these levels throughout analysis of the test samples.

Absorbance readings of the five calibration solutions for the standard curve were measured against a sulphuric acid (0.5M)/sodium sulphate (0.3% w/v) solution blank. Three consecutive absorbance readings (at three second intervals for copper and chromium and five second intervals for arsenic) were then recorded for each test sample and the machine zeroed with

distilled water between each sample. The sensitivity of the machine was checked at regular intervals by testing the individual standards, and if any change occurred a new calibration curve was obtained by repeating absorbance measurements of the five calibration solutions.

Calculation of metal concentrations from absorbance data was handled by computer. Data from calibration standards was used to obtain the best straight line for the concentration against absorbance curve (programme in basic, by Lee and Lee, 1982) which was then used to convert test sample absorbance data to sample metal concentration. The metal concentration (ug/ml) was then expressed as % w/w of the metal in the original wood sample using the calculation shown in Appendix I.

2.2.2.4. Statistical Analysis of Data.

The following statistical comparisons were undertaken on CCA measurements obtained from the poles during their first three years of field exposure:-

(i) Depth of CCA penetration was determined for each of the ten cores removed at a height of 1m from poles of each of the four wood species after three years field exposure. Depth of penetration was defined as the core depth at which copper, chromium and arsenic ceased to be detected by AAS analysis. These depth measurements were then statistically compared by analysis of variance to determine if significant inter-species differences existed.

(ii) Levels of CCA retention (i.e. total CCA salt content) over a

40mm standard core length were calculated for each of the ten cores removed at a height of 1m from poles of each of the four wood species after three years field exposure. Analysis of variance of the data was undertaken to determine if significant inter-species differences in preservative loadings existed.

(iii) Permanence of the CCA elements within the poles was examined by statistically comparing the copper, chromium and arsenic measurements recorded at the groundline over the three year period of field exposure. Each metal was examined separately by comparing the radial concentration profiles in cores removed from poles of each individual wood species. Measurements recorded after 1, 2 and 3 years field exposure were compared with each other, then individually compared to the copper, chromium and arsenic levels reported prior to field implantation (Evans et al., 1987a).

2.2.3. Examination of Longitudinal Variation in CCA Levels.

After four years field exposure, the poles were examined for differences in levels and radial distribution of CCA components at three sampling heights. The two poles of each species which were sampled prior to field exposure by Evans et al (1987a) were selected to give a direct comparison with original preservative measurements.

The poles were sampled at the groundline and heights of 3.5m and 6.5m above groundline. Three cores were removed at equidistant points around each pole at the three heights to give

72 core samples in total (i.e. 2 poles x 4 wood species x 3 heights x 3 replicates). Radial distribution of the preservative elements was examined by sectioning of the cores according to the plan in Figure 2.3 and subsequent extraction of the metals was undertaken by the method described in section 2.2.2.2. The concentration of metals in the wood was then determined by atomic absorption spectrophotometry as described in section 2.2.2.3.

Copper, chromium and arsenic measurements recorded at the three sampling heights after field exposure were statistically compared with each other to determine if significant longitudinal differences existed within any of the wood species examined. The concentration of individual elements across the radial profile of cores after 4 years exposure were then compared with those recorded prior to pole implantation (Evans et al., 1987a) to determine if significant changes had occurred during field exposure.

2.2.4. Measurement of Preservative Elements in Soil.

2.2.4.1. Soil Sampling.

2.5 years after pole implantation, small soil samples were removed from adjacent to the poles for analysis of their copper, chromium and arsenic content.

Two soil samples were removed from adjacent to each of the twenty poles, corresponding to their 'wet' and 'dry' sides. The 'wet' side was defined as the region of the pole facing the direction of the prevailing wind and would therefore be expected

to receive the greatest amount of rain. The 'dry' side represented the position directly opposite the 'wet' sampling point.

The sampling regime used to remove the soil is shown in Figure 2.4. A block of soil approximately 200 x 200mm (sample A) was removed from immediately adjacent to the pole surface, using a spade. A thin scraping of soil was discarded from the surface which had been in direct contact with the pole to remove any salt deposits originating from the wood surface. A small sample (15-20g) was then removed at a depth of 100mm below ground, extending 0-10mm from the newly exposed surface which had been previously adjacent to the wood.

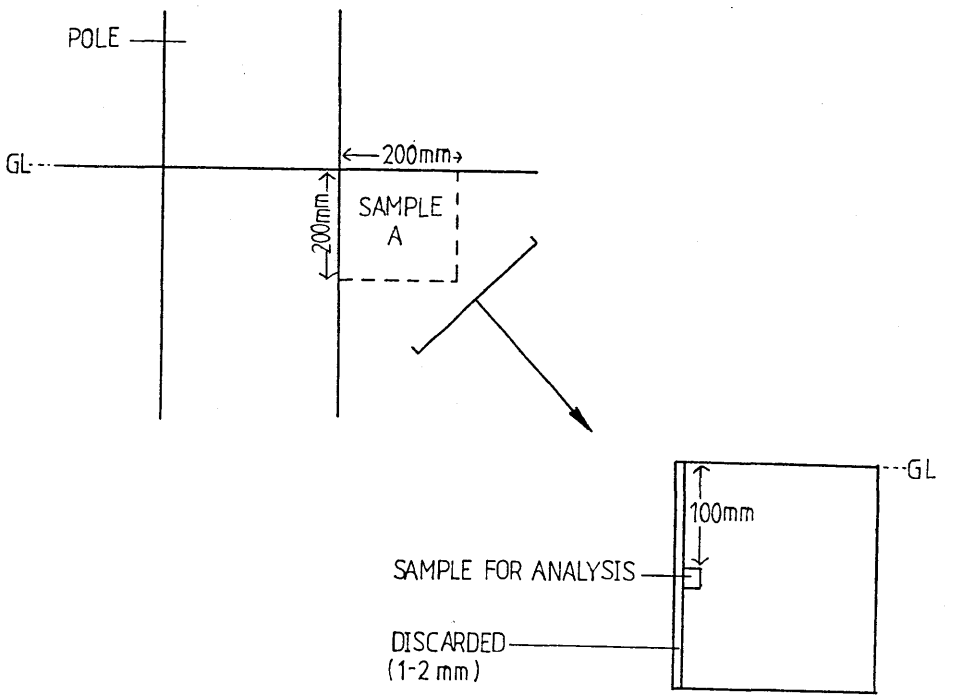


Figure 2.4. Diagram of the sampling regime used to remove soil from adjacent to the field poles.

Twelve control samples were also removed at a depth of 100mm below groundline at the central position of each set of four poles (at least 2.5m from any pole) within the pole site. A total of 40 test samples (from the 'wet' and 'dry' sides of the twenty poles) and 12 control samples were therefore collected for metal analysis.

2.2.4.2. Recovery of Metals from Soil.

Prior to analysis of the test samples, the technique for extraction of copper, chromium and arsenic from the soil was validated by measuring recoveries of known amounts of the preservative elements added to soil sampled from the same field site.

Soil removed from the field site (identified as a slightly clay-based sandy loam) was air-dried and sieved to pass a 2mm mesh. The sample was divided into two equal portions. A known amount of 0.5% CCA Type II solution was added to one portion and an equivalent volume of distilled water added to the other (for measuring background levels of copper, chomium and arsenic). The soil was left overnight then dried in an oven at $103\pm2^{o}C$, ground using a mortar and pestle, re-dried and divided into six replicate portions. The copper, chromium and arsenic content of the soils were then extracted using a modified version (Green, 1988) of the B.S. 5666 method described earlier (section 2.2.2.2) i.e. increased volume of sulphuric acid and increased extraction temperature.

The weighed soil was transferred to a 100ml conical flask with 40ml sulphuric acid (2.5M) and 4ml hydrogen peroxide (100 volumes) and heated to 85^{o}C for 30 minutes with frequent mixing. After heating, 40ml distilled water and 10ml sodium sulphate (3% w/v) were added and the material filtered through a Whatman No.541 filter paper into a 100ml volumetric flask. The soil was washed several times with distilled water and the final solution adjusted to 100ml with distilled water. Two methods of metal analysis were then compared.

2.2.4.3. Analysis of Metals in Soil.

Calibration Curve Method.

The copper, chromium and arsenic contents were measured according to the procedure described in 2.2.2.3. The absorbance readings of each test solution were measured and compared to calibration curves from the standard solutions to determine the concentration of metal in the soil, as shown in Appendix I.

Standard Additions Method.

Three 20ml aliquots of each extracted solution were transferred to separate 25ml volumetric flasks labelled A, B and C. 1ml of a standard solution containing 25ug/ml copper and chromium and 250ug/ml arsenic, was added to flask B while 2ml of the same standard solution was added to flask C. All three flasks were then adjusted to 25ml with a sulphuric acid (0.5M)/sodium sulphate (0.3%) solution. The absorbance of each set of sample solutions (A,B,C) were then obtained using the AAS

method described in section 2.2.2.3.

The concentration of the three metals in flask A i.e. without added standard, was determined by plotting the absorbance of the three samples (A, B and C) against the amount of the metal added i.e. 0, 1 and 2ug of copper and chromium, and 0, 10 and 20ug of arsenic, using the computer programme described in section 2.2.2.3. The negative of the x-intercepts represented the amount of each metal in the 25ml of flask A. The concentrations of copper, chromium and arsenic in flask A were then used to calculate the %w/w of the elements in the original soil samples. A worked example of this type of calculation is given in Appendix II.

Background levels of the three metals (from analysis of control samples) were subtracted from metal concentrations in the test samples to give the amount of each metal added to the soil i.e. metal recovery. The concentration of each metal determined by the two analysis methods was compared to the expected values (calculated from the amount of CCA initially added to the soil) and the percentage recovery determined. These results are presented in Table 2.2 and show the standard additions method to give the most accurate measurements. Each of the 40 test and 12 control samples were therefore analysed by this method.

Table 2.2. Mean percentage recovery of copper, chromium and arsenic from soils after analysis by the calibration curve and standard additions methods.

Analysis Method	Metal Recovery / %		
	Copper	Chromium	Arsenic
Calibration Curve	95.6	84.4	67.7
Standard Additions	96.6	90.3	115.5

2.2.4.4. Statistical Analysis of Soil CCA Levels.

A statistical 't' test was used to determine if soil samples removed from the 'wet' and 'dry' sides of poles of each species were significantly different. Comparison of the test sample data ('wet' and 'dry' samples combined) with the control data was then undertaken by analysis of variance to determine if significantly higher levels of copper, chromium or arsenic were present in the soil adjacent to poles of the four wood species compared with background levels.

2.2.5. Measurement of the Acidity of Rainwater.

Two rainwater samples were collected in the vicinity of the field site in order to determine their pH measurements. The rain was collected in two 1 litre plastic bottles (PVC) which had filter funnels (100mm diameter) inserted into their necks and

sealed with tape. The bottles were partially buried in the ground (for stability) at sites 10m from each other and 3m from the pole layout and were left for two weeks during a very wet period. Rainwater collected within the bottles was then filtered to remove any plant debris and its pH determined using a calibrated pH meter.

2.2.6. Determination of Moisture Profiles.

Radial moisture profiles of cores removed from field poles were used to examine differences in moisture content of the four treated wood species.

After four years field exposure, and during a relatively wet period, core samples were removed from the twenty poles for measurement of their radial moisture profiles. Single 100mm cores were removed at the groundline region and at a height of 1m from the five poles of each wood species. Each core was sectioned according to the plan in Figure 2.5 and the wet weight of each section determined. After drying at $103 \pm 2^{\circ}C$, the sections were re-weighed.

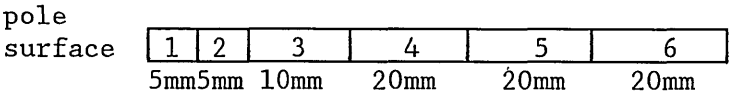


Figure 2.5. Core sectioning pattern for moisture determinations in each of the four wood species.

Percentage moisture contents (on a dry weight basis) were then calculated according to the following equation:-

$$\% \text{ moisture content} = \frac{\text{wet weight(g)} - \text{dry weight(g)}}{\text{dry weight(g)}} \times 100\%$$

2.2.7. Comparison of Extent of Checking in the Four Wood Species.

After four years field exposure, and during a relatively wet period, the frequency, width and depth of all checks between the groundline and 1m were recorded for each of the twenty poles. The depth of the checks were measured by the insertion of a very thin metal ruler, but those less than 1mm in width were not recorded.

2.2.8. Isolation and Identification of Fungal Colonisers.

After four years field exposure, duplicate cores were removed from the groundline region of each of the twenty poles for isolation of fungal colonisers. The cores were removed 60° to the vertical, using a flame sterilised Mattson auger. Sampling was carried out adjacent to checks, where possible, and the cores placed immediately into sterile screw-capped test-tubes.

In the laboratory, the cores were sectioned at the border of untreated and CCA-treated wood and each portion placed separately onto plates of 3% malt extract agar (Oxoid No. CM59)*. The plates were incubated at 25°C, examined daily and pure cultures of all fungal organisms obtained after subculturing onto fresh plates of 3% malt extract agar.

* containing 0.1% streptomycin sulphate.

Identification of the fungal isolates was undertaken by:

(i) examination of cultural and microscopic characteristics and identification of deuteromycetes using an appropriate taxonomic key (Barnett, 1955).

(ii) those isolates identified as basidiomycetes by cultural and microscopic characteristics were categorised as either brown or white rot organisms by observing their effect on agar containing tannic acid using the method described by Nobles (1964).

(iii) those isolates which remained unidentified were sent to CAB International, Mycological Institute, Surrey for positive identification.

Poles were also continually examined for any visual signs of decay. All cores removed from the poles for preservative measurements, moisture levels or fungal isolations were examined visually for signs of internal decay. Additionally, during removal of large soil blocks required for analysis of metals levels in soil (section 2.2.4.1), the newly exposed pole surfaces were examined for development of soft rot decay.

2.3. RESULTS.

2.3.1. CCA Loading, Penetration, Distribution and Permanence.

The radial distribution of copper, chromium and arsenic in samples removed from the groundline and a height of 1m from the poles after 1, 2 and 3 years field exposure, together with the values prior to field exposure reported in Evans et al (1986b, 1987a), are presented in Figures 2.6 - 2.9. Measurements prior to field exposure (year 0) represent an average of 12 core samples (6 replicates from 2 poles), whilst those after field exposure represent the average of 10 core samples (2 replicates from 5 poles). Metal concentrations recorded as percentage weight/weight (metal/wood), are also represented in Appendix III (Tables 1-4) with respective standard deviation values. Radial profiles of total CCA salt loadings for the four wood species are presented in Figure 2.10. These values are given as kg/m^3 (preservative/wood) and were calculated using sapwood densities determined by Evans et al (1988). The density values for the four species were reported as:-

Corsican pine - $0.352 g/cm^3$

Scots pine - $0.373 g/cm^3$

Norway spruce - $0.368 g/cm^3$

Sitka spruce - $0.373 g/cm^3$

Total salt loadings (Figure 2.10) show a general decrease from pole surface to pole centre in all four wood species. Comparing this pattern with the radial distribution of the

The legends below refer to Figures 2.6 - 2.9 on the following pages:-

Figure 2.6. Copper, chromium and arsenic retentions in cores sampled at the groundline and a height of 1m from Corsican pine poles after 0, 1, 2 and 3 years field exposure.

Figure 2.7. Copper, chromium and arsenic retentions in cores sampled at the groundline and a height of 1m from Scots pine poles after 0, 1, 2 and 3 years field exposure.

Figure 2.8. Copper, chromium and arsenic retentions in cores sampled at the groundline and a height of 1m from Norway spruce poles after 0, 1, 2 and 3 years field exposure.

Figure 2.9. Copper, chromium and arsenic retentions in cores sampled at the groundline and a height of 1m from Sitka spruce poles after 0, 1, 2 and 3 years field exposure.

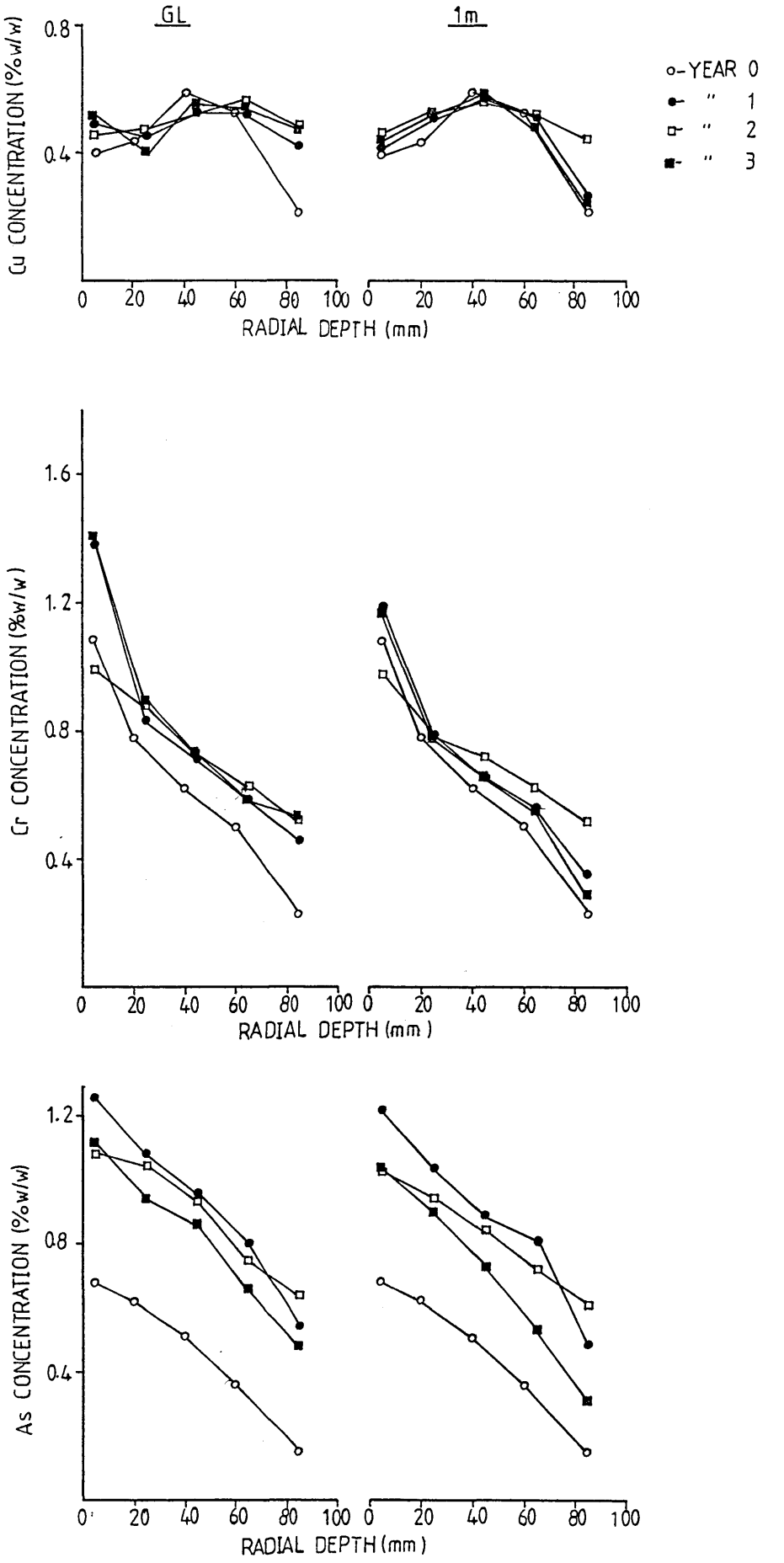


FIGURE 2.6: CORSICAN PINE

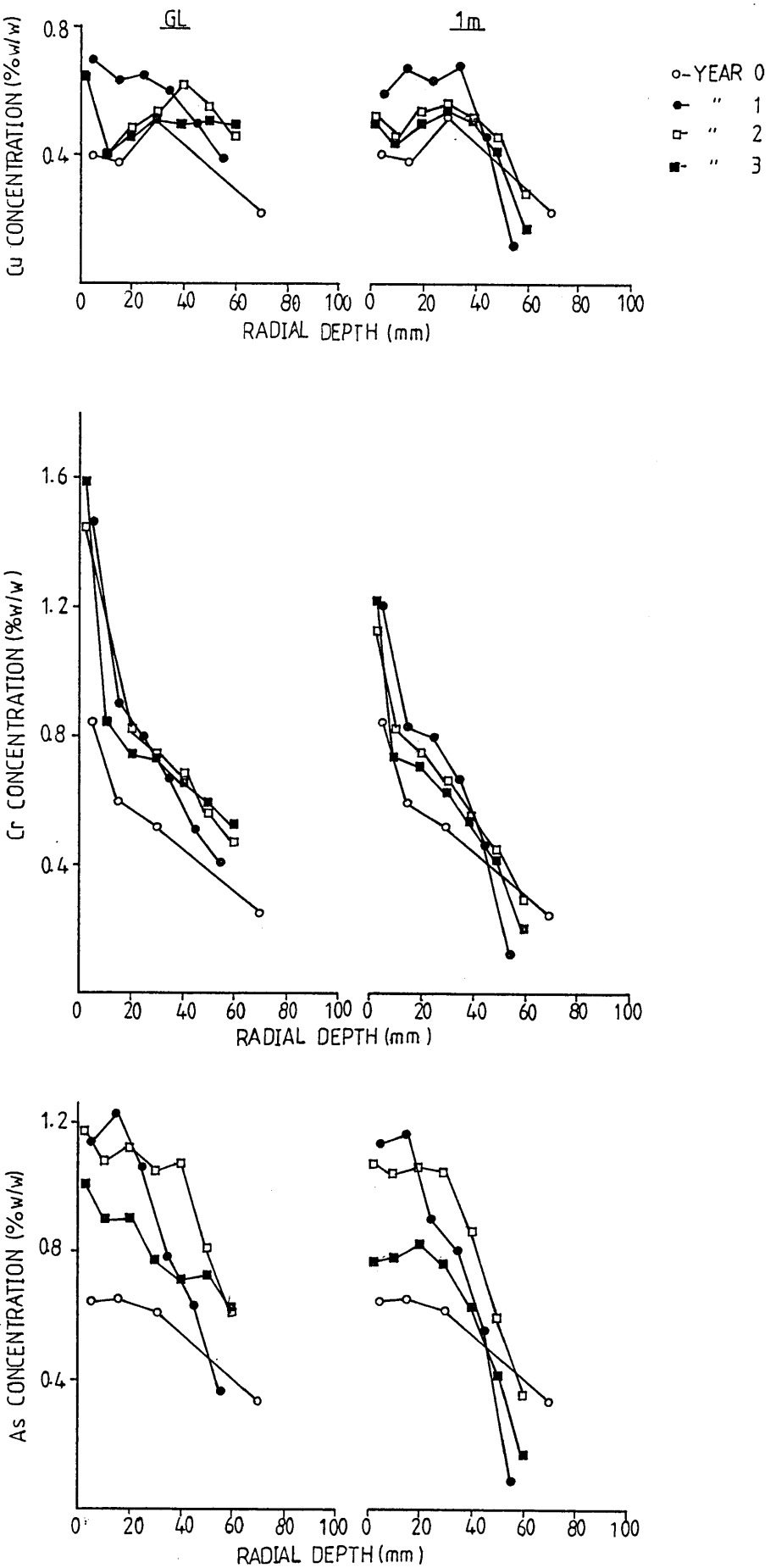


FIGURE 2.7 : SCOTS PINE

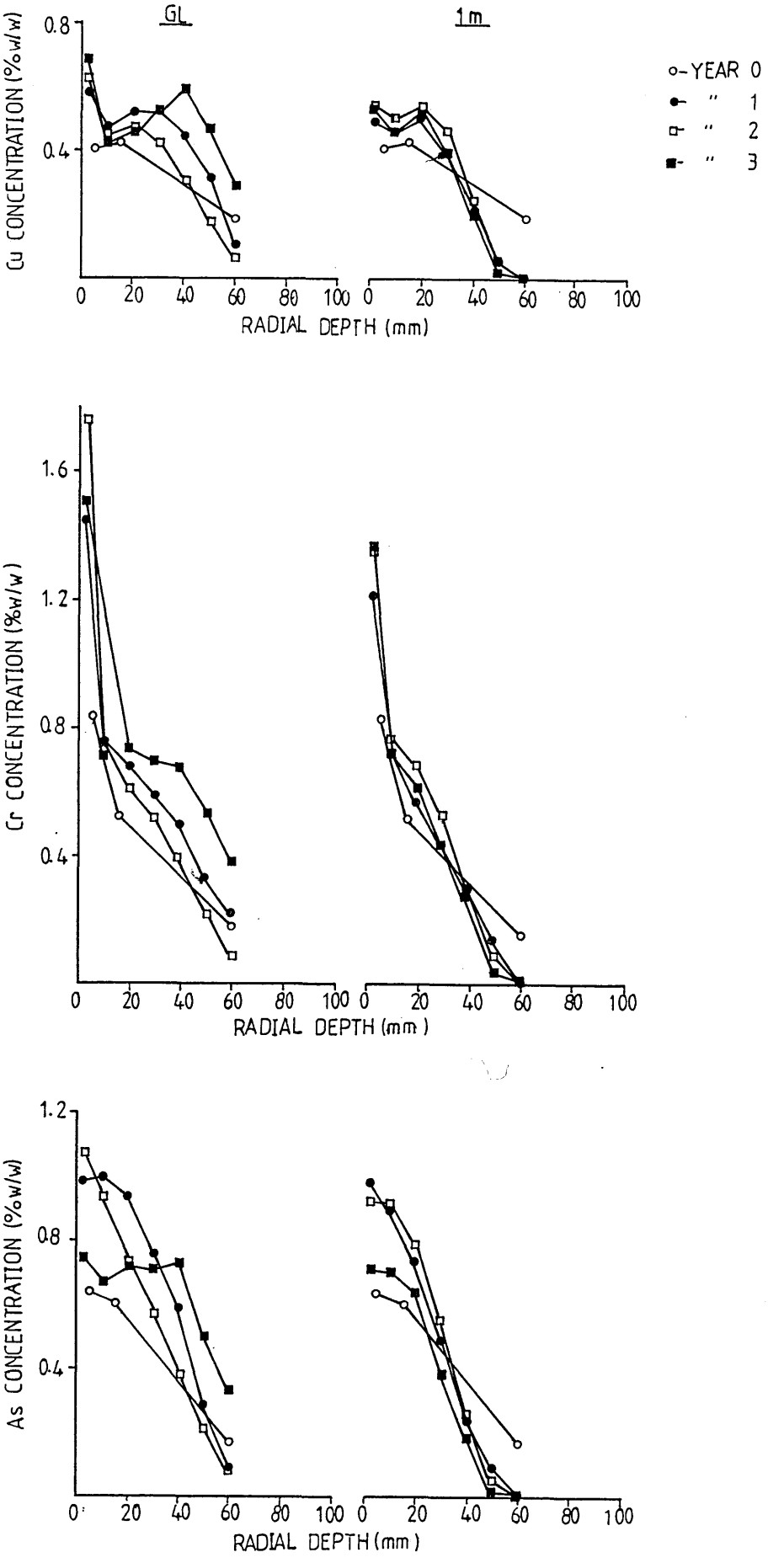


FIGURE 2.8: NORWAY SPRUCE

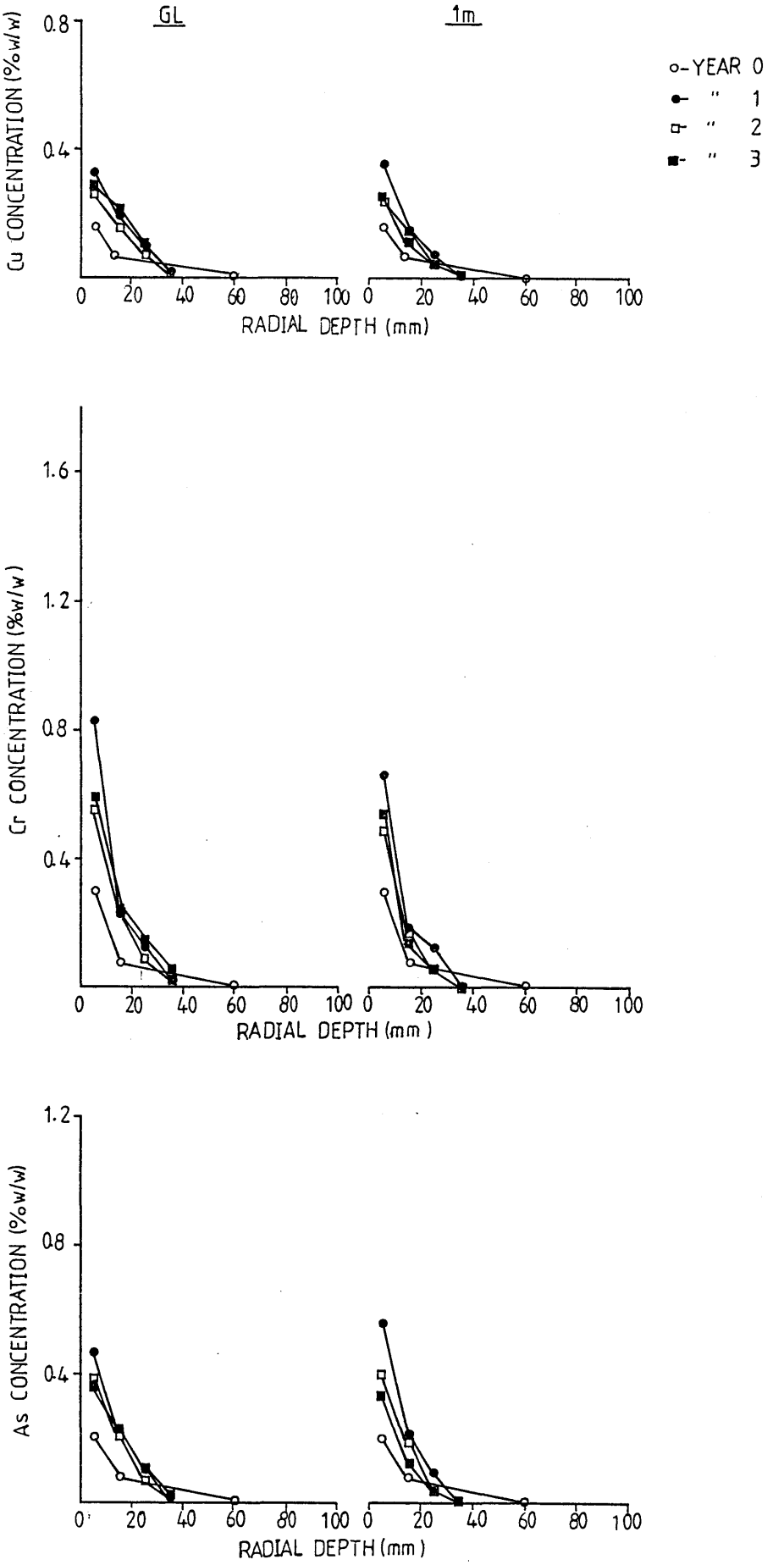


FIGURE 2.9 : SITKA SPRUCE

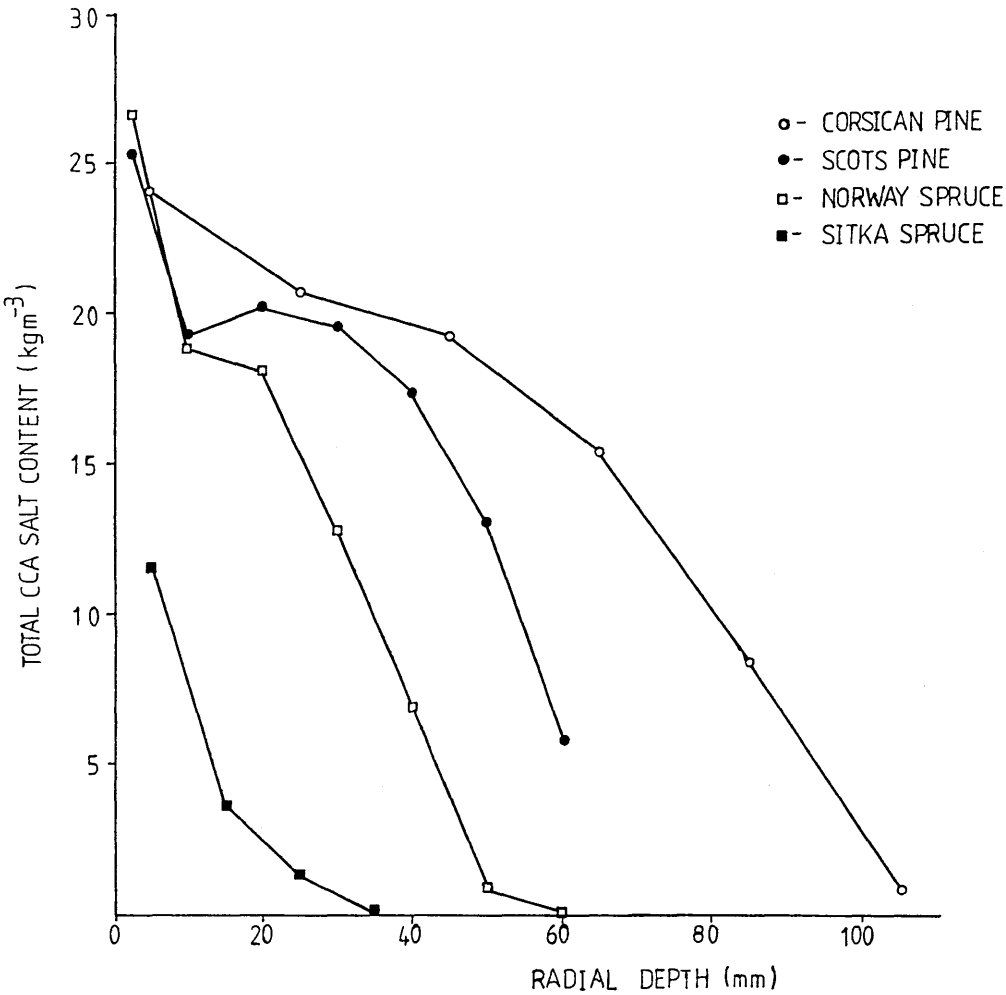


Figure 2.10. Radial profiles of total CCA salt content in cores sampled at a height of 1m from poles of the four wood species after 3 years field exposure.

individual preservative components (Figures 2.6 - 2.9) shows chromium and arsenic to possess similar radial patterns, however, in Corsican pine, Scots pine and Norway spruce, an intermediate peak in copper concentration is seen at varying radial depths from the pole surface. This copper peak is not apparent in Sitka spruce poles.

The ratio of copper, chromium and arsenic salts in cores removed from poles of the four wood species after one years field exposure, are presented in Table 2.3. This data shows disproportionation of the CCA salt components when compared to the nominal ratio of 35:45:20, for copper, chromium and arsenic salts, respectively. A slight reduction in the proportion of copper is observed at the surface of the poles (<35%) which gradually increases with increasing radial depth, to a maximum of 46%. Chromium was found to show a corresponding decrease from pole surface to pole centre, whilst arsenic generally showed a higher proportion than the original treating solution with a peak at a distance of 10-20mm from pole surfaces. The disproportionation of copper correlates well with the position of the peak in copper concentration observed in Corsican pine, Scots pine and Norway spruce poles (Figures 2.6 - 2.8). Although this type of peak was not observed in Sitka spruce poles (Figure 2.9), copper levels were still seen to increase above the nominal proportion with increasing radial depth (Table 2.3).

Differences in the levels of retention and depths of penetration of CCA salts within the four wood species are apparent from Figure 2.10. Corsican pine, Scots pine and Norway spruce poles show much greater preservative retentions and

Table 2.3. Ratio of copper, chromium and arsenic salts in cores removed from poles of the four wood species (cores removed from the groundline of poles after 1 years field exposure).

Radial Depth /mm	% Salt Ratio		
	Copper :	Chromium :	Arsenic
Corsican pine			
0 - 10	23.6	48.6	27.8
20 - 30	28.9	39.2	31.9
40 - 50	35.5	35.0	29.5
60 - 70	39.5	32.4	28.1
80 - 90	41.6	33.6	24.8
Scots pine			
0 - 10	30.8	46.4	22.8
10 - 20	34.8	35.2	30.0
20 - 30	38.1	33.5	28.3
30 - 40	42.2	33.1	24.7
40 - 50	43.6	31.5	24.9
50 - 60	46.0	34.6	19.4
Norway spruce			
0 - 5	28.1	50.4	21.6
5 - 15	32.1	37.2	30.7
15 - 25	36.3	34.0	29.7
25 - 35	40.3	32.9	26.8
35 - 45	41.3	33.9	24.8
45 - 55	46.0	35.1	18.9
Sitka spruce			
0 - 10	31.4	47.8	20.8
10 - 20	40.8	35.9	23.3
20 - 30	40.6	39.4	20.0
30 - 40	45.9	32.9	21.2

Nominal ratio of copper:chromium:arsenic salts was 35:45:20.

penetrations, than Sitka spruce poles. Statistical analysis was carried out to determine whether the differences in both retention and penetration were significantly different between the four wood species.

CCA Penetration.

Average depths of CCA penetration for the ten cores removed at a height of 1m from poles of each wood species after 3 years field exposure are presented in Table 2.4. Depth of penetration was determined from AAS analysis of cores sectioned according to Figure 2.3, and therefore measured to the nearest 10mm. Consequently, quite large standard deviation values were recorded for each wood species (Table 2.4).

Analysis of variance of the CCA penetration data showed Corsican pine to have significantly greater depths of CCA penetration ($p < 0.005$) than each of the other wood species. Similarly, Sitka spruce was found to have significantly lower depths of CCA penetration ($p < 0.0005$) than each of the other three species. Depth of penetration measurements for Scots pine and Norway spruce were not found to be significantly different ($p > 0.05$). A ranked order for CCA penetration in the four wood species would therefore be Corsican pine > Scots pine = Norway spruce > Sitka spruce. Figure 2.11 shows a photograph of the radial faces of pole segments treated by sap-displacement, and clearly shows the differences in CCA penetration between the four wood species.

Table 2.4. Mean depths of CCA penetration in poles of the four wood species after 3 years field exposure.

Wood Species	Depth of CCA Penetration / mm
Corsican pine	100.0 ± 15.12
Scots pine	68.8 ± 11.88
Norway spruce	54.0 ± 8.76
Sitka spruce	29.0 ± 7.38

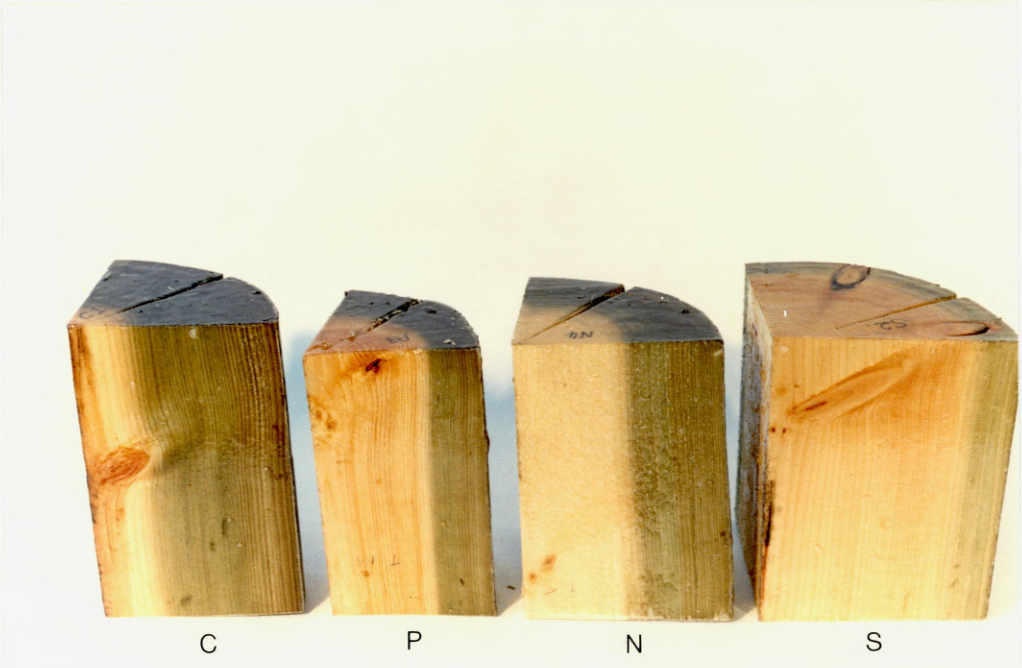


Figure 2.11. Radial faces of pole segments of Corsican pine (C), Scots pine (P), Norway spruce (N) and Sitka spruce (S), showing variability in depth of CCA penetration.

CCA Retention.

Since CCA penetration varies significantly between the four wood species, for the purposes of comparing the levels of CCA retention it was decided to standardise the wood cores to a uniform length of 40mm. Consequently, only the CCA content of the outermost sapwood was compared, thereby eliminating the effect of variable depth of penetration. CCA retention values were calculated for the ten cores removed at a height of 1m from poles of each wood species after 3 years field exposure. Mean CCA salt retentions are presented in Table 2.5.

Table 2.5. Mean CCA salt retentions in outer 40mm of cores sampled from poles of each wood species after 3 years field exposure.

Wood Species	Total CCA Content / kg/m^3
Corsican pine	24.73 ± 2.521
Scots pine	21.93 ± 2.688
Norway spruce	18.54 ± 3.732
Sitka spruce	4.52 ± 2.365

Analysis of variance to determine the effect of wood species on preservative loading showed a significant difference ($p < 0.05$) between Corsican pine, Scots pine and Norway spruce. Sitka spruce was found to be very significantly different ($p < 0.0005$) from each of the other three wood species. Rating of the extent

of preservative retention can therefore be summarised as Corsican pine > Scots pine > Norway spruce > Sitka spruce.

2.3.2. Preservative Permanence During Field Exposure.

A study of preservative permanence within the field poles was possible by comparing the copper, chromium and arsenic profiles recorded over the three year period (Figures 2.6 - 2.9). The graphs indicate that at both groundline and 1m sampling positions, preservative levels after field exposure are generally higher than those reported by Evans et al (1987a) prior to the poles being erected. In most cases these increased levels were found across the entire radial profiles of the poles. In the spruce species however, it would appear that higher CCA retentions were recorded to greater penetrative depths in the year 0 samples. This anomaly is due to different core sampling procedures used in the earlier study by Evans et al (1987a), as mentioned in 2.2.2. At year 0, Evans et al (1987a) analysed a larger part of the cores as a single sample and subsequently reported an average CCA retention value at a depth beyond the actual penetration of the salts found in this study. Analysis of the cores after 1, 2 and 3 years field exposure gave a more detailed representation of the depth of penetration due to a more comprehensive sectioning procedure.

Statistical analysis of preservative retentions was undertaken to determine whether the apparent differences in levels of copper, chromium and arsenic before and after field exposure (Figures 2.6 - 2.9) were significant. Within each wood

species, the copper, chromium and arsenic levels measured at the groundline prior to field exposure were compared separately against results recorded after 1, 2 and 3 years field exposure. Data from years 1, 2 and 3 were then compared to each other. Table 2.6 summarises the results of the statistical analysis of data for the four wood species.

Table 2.6. Statistical comparison of copper, chromium and arsenic levels before and after field exposure.

Wood Species	Comparison	PROBABILITY		
		Copper	Chromium	Arsenic
Corsican pine	yr 0 v's yr 1	NS	+	+++
	yr 0 v's yr 2	+	+	+++
	yr 0 v's yr 3	+	+	+++
	yrs 1, 2 & 3	NS	+	++
Scots pine	yr 0 v's yr 1	+++	+++	+++
	yr 0 v's yr 2	+++	+++	+++
	yr 0 v's yr 3	+	+++	+++
	yrs 1, 2 & 3	++	NS	++
Norway spruce	yr 0 v's yr 1	+++	++	+++
	yr 0 v's yr 2	+	+	+
	yr 0 v's yr 3	+++	+++	+++
	yrs 1, 2 & 3	++	+	++
Sitka spruce	yr 0 v's yr 1	++	++	++
	yr 0 v's yr 2	+	+	+
	yr 0 v's yr 3	+++	++	++
	yrs 1, 2 & 3	NS	NS	NS

v's = versus
yr = year
\+ = probability value of < 0.05] probability that retention
++ = probability value of < 0.005] values were from the same
+++ = probability value of < 0.0005] population.
NS = no significant difference between retention values (i.e. $p > 0.05$)

Analysis of pre- and post-implantation levels of copper, chromium and arsenic (Table 2.6) shows that in most cases, the preservative concentration at year 0 is significantly different from the measurements taken during the three years of field exposure. One exception to this finding was the comparison of copper levels in Corsican pine poles after 0 and 1 years field exposure where no significant difference was noted.

Comparison of the preservative levels in the four wood species at the three sampling times during field exposure gave no consistent pattern of results. In the case of Sitka spruce there was no significant difference in the levels of each of the three metals in the poles after 1, 2 and 3 years exposure. Corsican pine showed no significant difference in the levels of copper, whilst Scots pine showed no difference in the levels of chromium over the period between year 1 and year 3. All other wood species/preservative component combinations produced small, but statistically significant differences between the three sampling times. While small differences did occur between years 1, 2 and 3, it is obvious from the results (Figures 2.6-2.9, and Table 2.6) that most of the changes occurred during the first year of field exposure.

2.3.2.1. Longitudinal Variations in Preservative Levels.

Sampling of the field poles at the two heights (groundline and 1m) showed radial concentration profiles from cores removed at the groundline to be generally higher than those sampled at a height of 1m (Figures 2.6 - 2.9). This effect suggests a possible

downward migration of the preservative salts during field exposure. To determine if this was a real effect, the poles were sampled at three points along their length and analysis carried out to determine any longitudinal variation in preservative levels.

Prior to erection of the twenty poles, Evans et al (1987a) randomly selected two of each species and removed cores at the groundline, 3.5m and 6.5m. Analysis of the preservative content of these cores showed there to be little longitudinal variation in the preservative loading from butt to top of poles of each wood species (Evans et al., 1987a). During this present study, the poles were re-sampled after 4 years field exposure and radial profiles of the three preservative components are presented graphically in Figures 2.12 - 2.15, alongside year 0 measurements. Measurements prior to field exposure (Evans et al., 1987a) represent an average of 12 core samples (6 replicates from two poles) whilst those after field exposure represent the average of 6 core samples (3 replicates from the same two poles). Metal concentrations are on a % weight/weight (metal/wood) basis, and are also represented with standard deviations in Appendix IV (Tables 1-4).

Distribution profiles for chromium and arsenic are shown to be similar to those in Figure 2.6 - 2.9, i.e. decreasing from pole surface to pole centre. In all cases, measurements recorded for chromium and arsenic at the groundline after four years exposure are higher than those recorded at 3.5m and 6.5m after four years, and at the groundline prior to field implantation. Figures 2.12 - 2.15 do however, show more irregularity in the

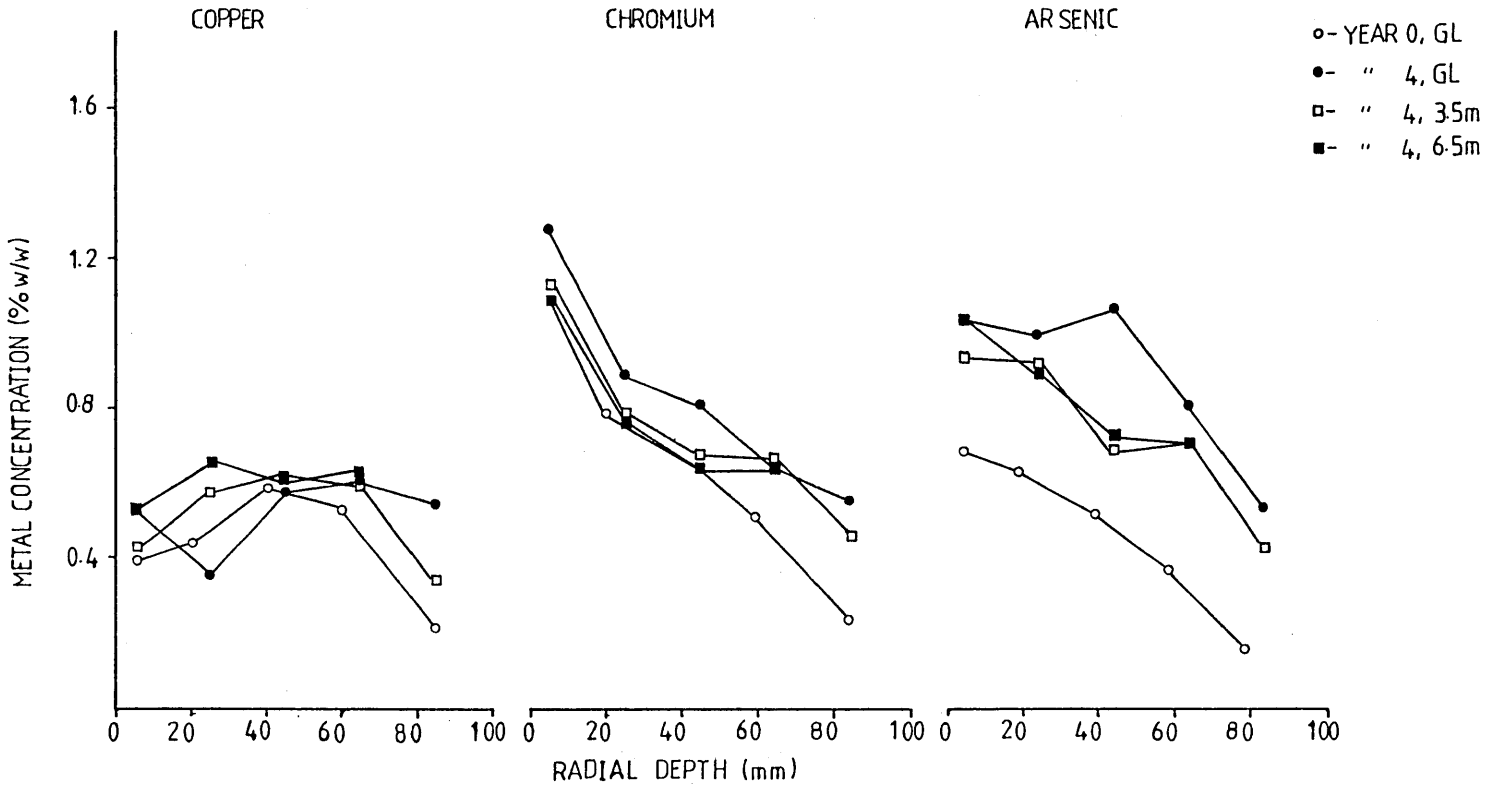


Figure 2.12. Copper, chromium and arsenic retentions in cores sampled at the groundline and heights of 3.5m and 6.5m from Corsican pine poles after 4 years field exposure. Measurements recorded at the groundline prior to field exposure (Evans et al, 1987a) are also presented.

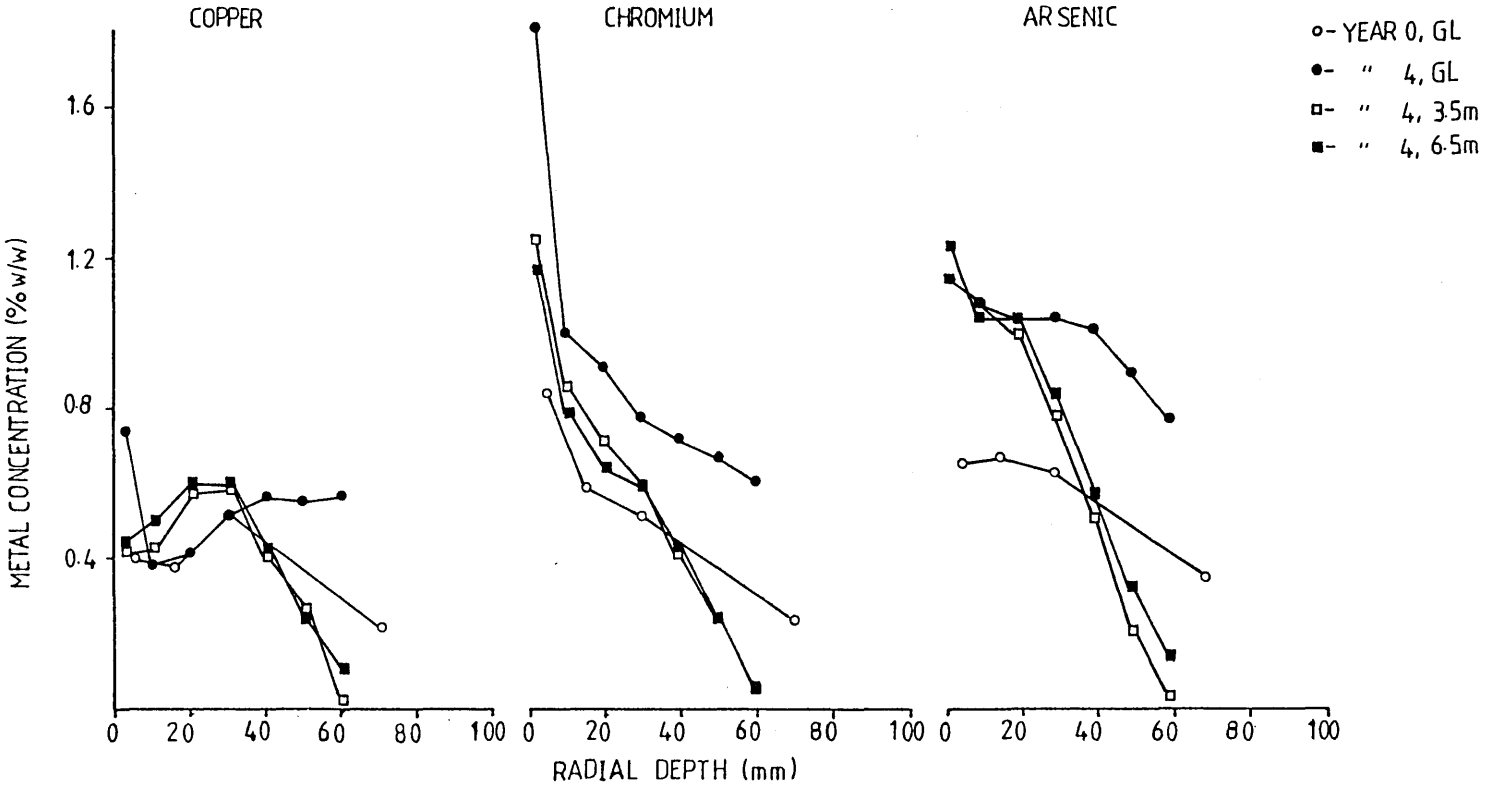


Figure 2.13. Copper, chromium and arsenic retentions in cores sampled at the groundline and heights of 3.5m and 6.5m from Scots pine poles after 4 years field exposure. Measurements recorded at the groundline prior to field exposure (Evans et al, 1987a) are also presented.

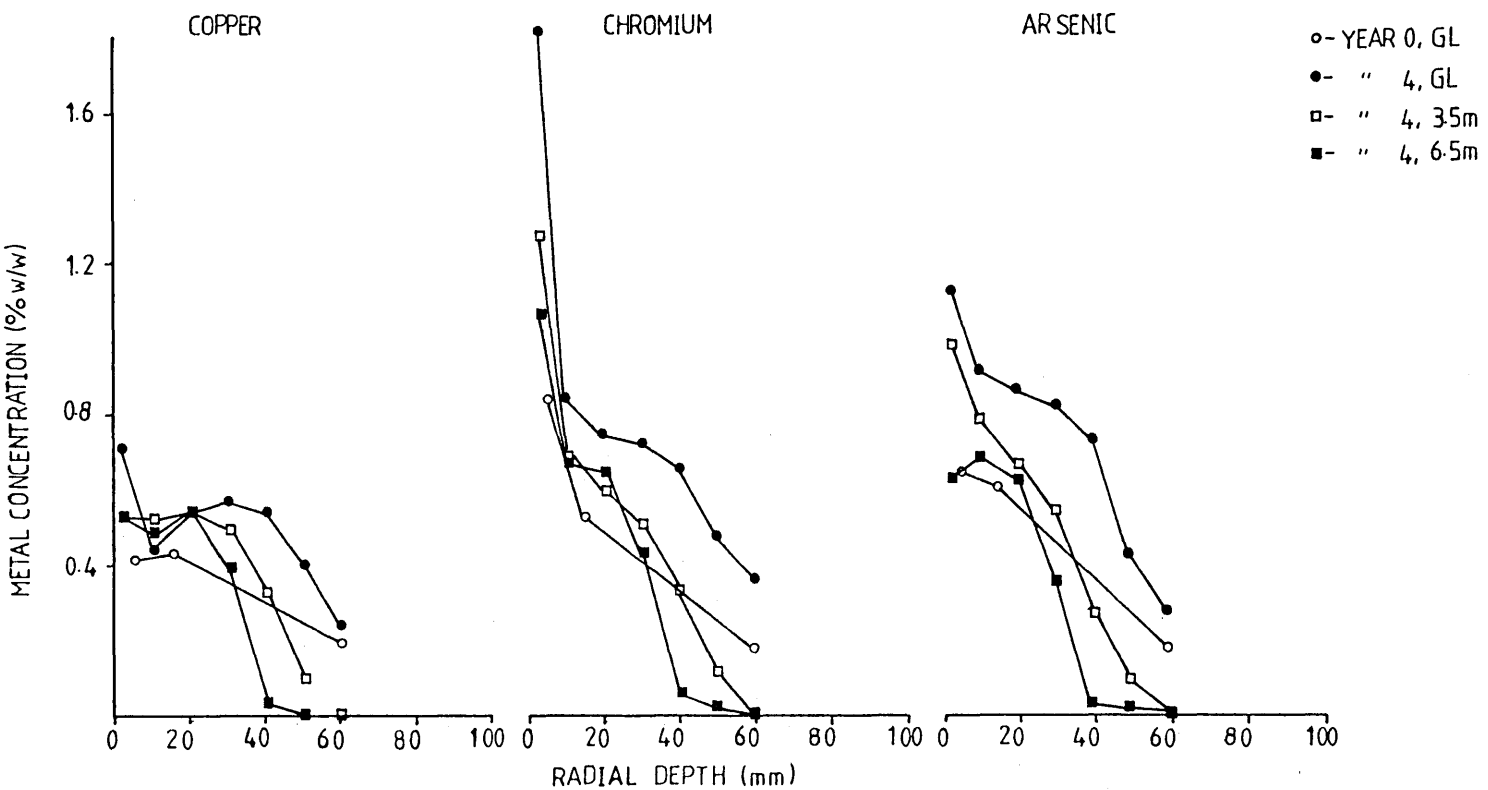


Figure 2.14. Copper, chromium and arsenic retentions in cores sampled at the groundline and heights of 3.5m and 6.5m from Norway spruce poles after 4 years field exposure. Measurements recorded at the groundline prior to field exposure (Evans et al, 1987a) are also presented.

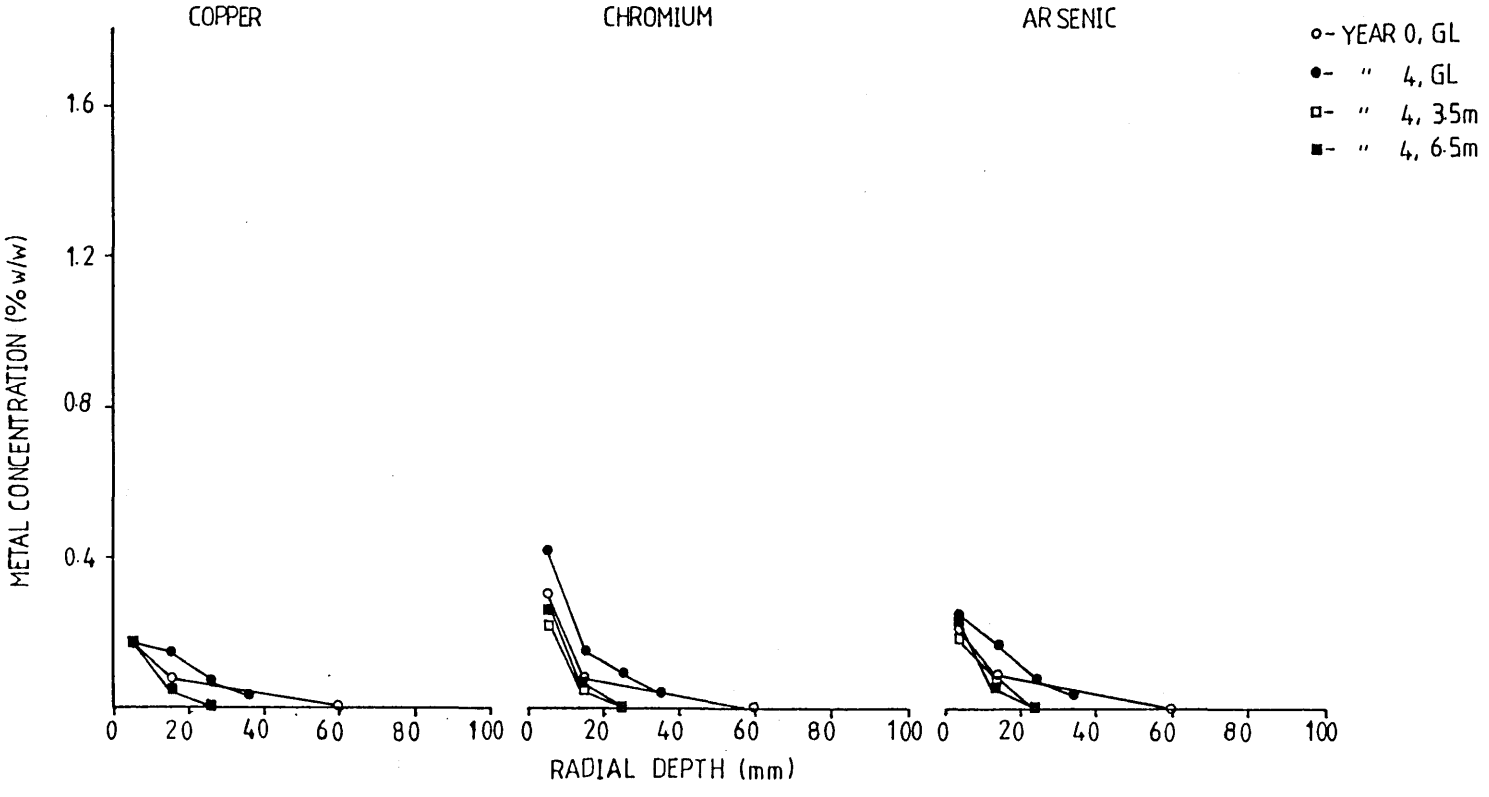


Figure 2.15. Copper, chromium and arsenic retentions in cores sampled at the groundline and heights of 3.5m and 6.5m from Sitka spruce poles after 4 years field exposure. Measurements recorded at the groundline prior to field exposure (Evans et al, 1987a) are also presented.

profiles for copper retention. As before, the radial distribution patterns show peaks in copper concentration in Corsican pine, Scots pine and Norway spruce poles. In each of these three species, the radial profiles at 3.5m and 6.5m after four years exposure are similar to each other, with the copper concentration peak at a similar distance from the pole surface. The groundline profiles however, show a definite change in copper radial distribution after 4 years field exposure. High levels of copper are present at pole surfaces, particularly in Scots pine and Norway spruce (Figures 2.13 and 2.14) which drop at around 10-20mm from the surface, but subsequently increase to higher levels at internal positions. This changing pattern of internal copper distribution can also be seen in Corsican pine, Scots pine and Norway spruce during the second and third year of sampling, particularly at the groundline (Figures 2.6 - 2.9). As shown previously, Sitka spruce poles do not show the presence of a peak in copper concentration (Figure 2.15), and concentration profiles show very little variation at the three sampling heights.

Increased levels of chromium at groundline pole surfaces are also evident after four years field exposure, particularly in Scots pine and Norway spruce poles (Figures 2.13 and 2.14)

Statistical analysis of the data was carried out to determine whether preservative retentions recorded at the three sampling heights were statistically different after four years exposure, and whether significant differences existed when year 0 samples were compared with the groundline, 3.5m and 6.5m measurements after 4 years exposure. These results are summarised in Table 2.7.

Statistical analysis of the data from Figures 2.12 - 2.15 shows that groundline levels recorded after four years exposure are in most instances higher than those measured at heights of 3.5m and 6.5m. In Corsican pine, Scots pine and Sitka spruce, no significant difference was observed between the 3.5m and 6.5m measurements, however, in Norway spruce, copper, chromium and arsenic levels were shown to decrease from pole butt to top. There were no initial differences at these three heights prior to field exposure (Evans et al., 1987a), indicating possible migration of the preservative components during field exposure.

Table 2.7. Statistical comparison of preservative element loadings at selected sampling heights prior to implantation and after four years field exposure.

Wood Species	Element	Comparison of data after 4 years exposure.	Comparison of pre- and post implantation data.
Corsican pine	Copper	gl = 3.5m = 6.5m	gl/3.5m/6.5m > yr0
	Chromium	gl = 3.5m = 6.5m	gl > yr0
	Arsenic	gl > 3.5m = 6.5m	gl/3.5m/6.5m > yr0
Scots pine	Copper	gl = 3.5m = 6.5m	gl > yr0
	Chromium	gl > 3.5m = 6.5m	gl > yr0
	Arsenic	gl > 3.5m = 6.5m	gl/3.5m/6.5m > yr0
Norway spruce	Copper	gl > 3.5m > 6.5m	gl > yr0
	Chromium	gl > 3.5m > 6.5m	gl > yr0
	Arsenic	gl > 3.5m > 6.5m	gl > yr0
Sitka spruce	Copper	gl > 3.5m = 6.5m	gl/3.5m/6.5m = yr0
	Chromium	gl > 3.5m = 6.5m	gl > yr0
	Arsenic	gl > 3.5m = 6.5m	gl/3.5m/6.5m = yr0

> - significantly higher than ($p < 0.05$).
= - not significantly different ($p > 0.05$).
yr0 - retentions recorded at the groundline region of poles prior to field exposure.
gl/3.5m/6.5m - retentions recorded at these heights after 4 years field exposure.

Comparison of the preservative levels after four years exposure with those reported by Evans et al (1987a) prior to pole exposure, show in most cases that groundline levels after field exposure are higher than those prior to implantation. In the case of Sitka spruce, however, where much lower preservative levels were consistently recorded, there was found to be no significant difference between pre and post-implantation levels.

2.3.2.2. Leaching of Preservative Components from Poles to Soil.

To monitor leaching of the CCA components from poles, soil sampled adjacent to each of the twenty poles was analysed for its copper, chromium and arsenic content. The concentrations of preservative components in soil sampled adjacent to the field poles are presented in Table 2.8. Values for test samples are the mean of five replicate samples (one sample from 5 poles), whilst those for background samples represent the mean of 12 replicate samples.

Initially, samples were removed from the 'wet' and 'dry' sides of each pole to determine if leaching was increased at the side exposed to the prevailing wind and rain direction. Statistical analysis of the data was undertaken using a 't' test, to determine if measurements recorded at 'wet' and 'dry' sides of poles were significantly different. The test showed there to be no significant difference between copper, chromium and arsenic levels measured at the 'wet' and 'dry' sides ($p > 0.1$). This result was consistent for all four wood species. The 'wet' and 'dry' measurements were therefore combined for further

Table 2.8. Concentration of copper, chromium and arsenic in soil sampled adjacent to poles treated with CCA by pressurised sap-displacement and exposed in the field for 2.5 years.

(a) 'Wet' sides of poles.

Species	Copper content ug/g soil	Chromium content ug/g soil	Arsenic content ug/g soil
Corsican pine	129.5±60.7	53.6±9.8	34.0±25.7
Scots pine	153.7±55.2	50.6±7.2	38.6±10.5
Norway spruce	160.7±104.9	56.4±14.6	37.7±15.4
Sitka spruce	227.0±136.2	72.6±19.2	31.5±20.8
Controls	37.2±3.0	35.5±1.3	23.7±10.8

(b) 'Dry' sides of poles.

Species	Copper content ug/g soil	Chromium content ug/g soil	Arsenic content ug/g soil
Corsican pine	165.6±153.0	57.5±16.3	39.3±25.8
Scots pine	206.9±118.3	59.8±11.2	27.4±14.2
Norway spruce	165.8±66.0	53.9±4.2	29.0±24.0
Sitka spruce	180.6±94.5	70.8±17.5	37.3±14.3
Controls	37.2±3.0	35.5±1.3	23.7±10.8

statistical analysis against background concentrations of the three metals.

Comparison of the test sample data with control data by analysis of variance, shows that copper and chromium levels in the soil adjacent to the poles of each species are significantly higher than background levels ($p < 0.001$ for both copper and chromium). Levels of arsenic in soils adjacent to the poles were not found to be significantly different from background concentrations ($p > 0.05$), however it must be noted that standard deviation values for arsenic measurements were very high.

Further statistical comparisons were undertaken to determine if greater concentrations of individual elements were found in the soil adjacent to particular wood species. The only statistically significant species effect which was found was the elevated chromium levels adjacent to Sitka spruce poles ($p < 0.05$).

2.3.3. Measurement of Acidity of Rainwater.

Rainwater samples collected in the vicinity of the field site were found to have an average pH measurement of 6.6 ± 0.11. Rain falling in this area could therefore be regarded as only very slightly acidic.

2.3.4. Moisture Distribution within the Poles.

Radial moisture profiles for poles of each of the four wood species are presented in Figure 2.16. Moisture measurements and standard deviations are recorded at the groundline and a height of 1m, with each measurement representing the mean of five replicates (1 core from 5 poles). Large standard deviation values in radial samples removed from the groundline (Figure 2.16), particularly in the pines, result from inter-pole variations in moisture uptake of the five poles of each species.

These moisture profiles show a dramatic species effect with the pines showing much higher moisture contents than the spruces, particularly at the groundline region of the poles. Moisture profiles are also consistently higher at the groundline than at a height of 1m, particularly in the pine species.

Radial distribution of moisture appears to be similar within the two pine species. At the groundline, both species have a relatively dry surface beneath which exists a peak in moisture content (~150%) at 15-20mm from the pole surfaces followed by a gradual decrease towards pole centres. At a height of 1m, however, moisture levels are much lower and show a very gradual decrease towards pole centres. Typical values at this sampling height fall within the range 30-40% for Corsican pine and 25-30% for Scots pine.

In contrast to the pines, moisture profiles at the groundline region of spruce poles were only slightly above those at 1m. The radial profiles are quite even from pole surface to pith, except for groundline measurements in Norway spruce where

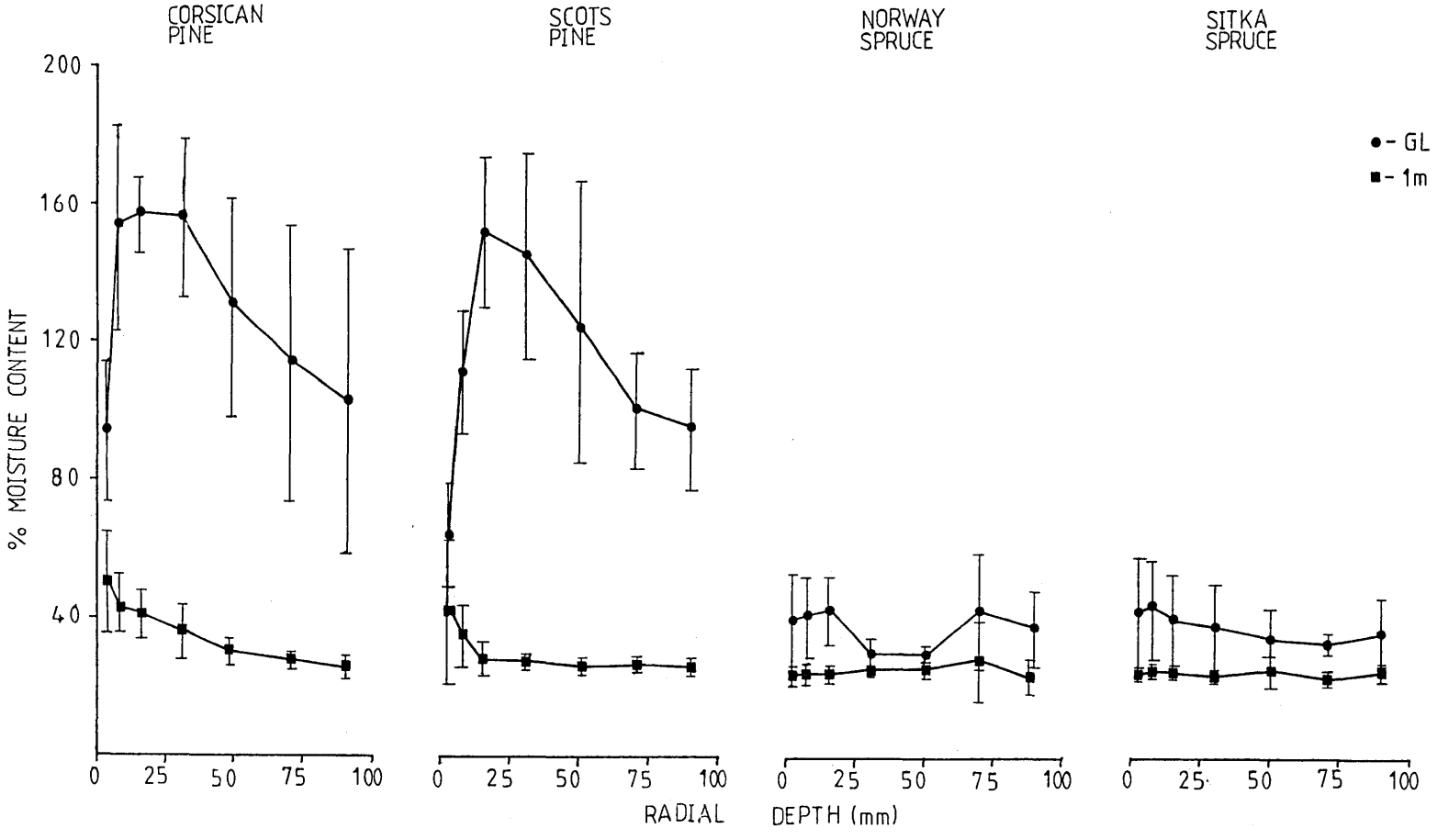


Figure 2.16. Radial moisture profiles in cores sampled at the groundline and a height of 1m from poles of the four wood species after 4 years field exposure.

elevated moisture contents were recorded at 60-70mm from the pole surfaces. Increases in moisture contents at this location correlate well with the average depth of CCA penetration as reported in Table 2.4.

2.3.5. Extent of Checking.

The frequency, width and depth of checks recorded between the groundline and 1m of poles of each of the four wood species are presented in Table 2.9. Results represent the total number of checks recorded in the five poles of each wood species.

Table 2.9. Total numbers and mean depths of checks recorded in the groundine region of poles of the four wood species (measured during a wet period).

Wood Species	CHECK WIDTH/MM					
	1		2		3	
	Total number of checks	Mean depth /mm	Total number of checks	Mean depth /mm	Total number of checks	Mean depth /mm
Corsican pine	0		0		0	
Scots pine	1	2.0	0		0	
Norway spruce	11	3.8±2.88	0		0	
Sitka spruce	40	5.8±4.17	11	19.5±11.49	2	34.0±21.21

Table 2.9 shows a definite species effect in both the numbers and depths of checks in poles of the four wood species. The pines had far fewer checks than the spruces, with only one check of 1mm width recorded for Scots pine and no checks recorded for Corsican pine. In contrast, checks were much more frequent and severe in spruce poles. Checks of 1mm in width were found in Norway spruce poles, with depths ranging from 2-12mm, whilst in Sitka spruce, check widths of up to 3mm were recorded. Although check measurements were recorded during a relatively wet period, depths of up to 49mm were found in Sitka spruce poles. Since CCA penetration in Sitka spruce often extends only 20-25mm, many of the recorded checks will enter the untreated region of the poles, thereby greatly increasing the likelihood of infection by spores of decay fungi.

2.3.6. Identification of Fungal Colonisers.

Fungal growth was recorded from both the untreated and CCA-treated portions of all cores removed from the field poles, with a wide variety of fungal species, particularly deuteromycetes, being isolated. Where possible, organisms were identified and the results are presented in Table 2.10.

Table 2.10. Fungal organisms cultured from CCA-treated and untreated regions of poles of the four wood species.

Fungal Isolate	Total Number of Isolates							
	Corsican		Scots		Norway		Sitka	
	T	U	T	U	T	U	T	U
Mucor spp.	3		7	2	4	5	6	8
Cephalosporium spp.	8							
*Alternaria alternata**	6		7	2	4	6	4	2
Fusarium spp.	4		2		1			
Hormoconis spp.	3		5		3	3	2	3
*Botrytis cinerea**			2		1	1		1
Penicillium spp.					1	1		
Unidentified white rot Basidiomycetes.							2	1
Unidentified moulds.		1	1	1			1	

T = CCA-treated region
U = untreated region
* = identified at CAB International, Mycological Institute, Surrey, England.

The most widely isolated organisms were *Mucor* spp. and *Alternaria alternata*. These species were isolated from both the treated and untreated regions of cores from each of the four wood species, apart from the untreated heartwood region of Corsican pine. It should be noted however, that due to the almost total lack of untreated material in Corsican pine, isolation of organisms was most unlikely from this region.

Three wood species produced an isolate which was unique to that particular timber type, namely *Cephalosporium* spp. in Corsican pine, *Penicillium* spp. in Norway spruce and the two basidiomycete organisms in Sitka spruce. The basidiomycete decay

fungi were isolated from both CCA-treated and untreated regions of cores, however in the case of the CCA-treated samples, growth of the organisms always occurred at the point furthest from the pole surface i.e. at the border of untreated and CCA-treated material where levels of CCA were at their lowest.

Comparison of fungal isolates from CCA-treated and untreated wood, irrespective of wood species, showed *Cephalosporium* spp., *Fusarium* spp., and one of the unidentified white rot organisms to be unique to CCA-treated material. None of the identified fungal isolates were found to be restricted to untreated regions of the poles.

Core samples removed from the poles throughout the field exposure period, i.e. cores for CCA and moisture determinations, were visually examined for signs of internal decay, however, no incidences of decay were observed. Similarly, visual examination of pole surfaces during the removal of large soil samples for soil metal analysis confirmed that no signs of soft rot development had occurred within the four year exposure period.

2.4. DISCUSSION.

2.4.1. Treatability of the Four Wood Species.

An important aspect of this study was to determine the quality of treatment of poles of the four wood species when treated with CCA by the sap-displacement process. Chemical analysis of the preservative within the poles showed wide variation in treatability of the four species. From Figure 2.10, it is apparent that Corsican pine, Scots pine and Norway spruce all show reasonable levels of CCA retention and penetration, however, much lower levels of retention and penetration were recorded in Sitka spruce poles. Statistical comparison of CCA penetration (Table 2.4) and retention within the outer 40mm of the poles (Table 2.5) showed significant differences between the four species and suggested an overall rating of treatability of Corsican pine > Scots pine > Norway spruce > Sitka spruce.

Reduced penetration and retention of CCA in Sitka spruce poles may be explained by several anatomical factors. Penetration of liquids into softwoods was reported to proceed from tracheid to tracheid via bordered pits, and to spread laterally through ray cells (Wardrop and Davies, 1961). In refractory species, such as Sitka spruce however, increased levels of pit aspiration and smaller proportions of ray tracheids (Liese and Bauch, 1967) result in reduced penetrability. Additionally, Sitka spruce poles consist of a very small proportion of sapwood and a large, impermeable heartwood core. Preservative penetration into Sitka spruce poles would therefore proceed at a much reduced rate

compared with the other species, particularly pines, resulting in much lower penetration depths. This reduced penetrability of CCA in Sitka spruce poles would also be expected to reduce the overall retention of salts within the outer treated sapwood band. Although the refractory behaviour of Sitka spruce greatly affected levels of retention and penetration in the poles, this effect was not observed in Norway spruce poles CCA-treated by sap-displacement. Penetration and retention of CCA in this species was found to be similar to Scots pine poles.

In terms of current British Standard regulations, all four species were adequately treated. B.S. 4072 (1987) currently specifies that all 'sapwood defined as permeable should be completely penetrated', and in B.S. 1990 (1984) it is stated that Norway and Sitka spruce cannot be adequately treated by standard procedures and should therefore be preserved using a modification of one of these procedures in order to meet the current penetration and retention specifications. However, it is evident that a minimum level of retention should also be specified, as was the case in the previous treatment standard (B.S. 4072, 1974), and in the present technical specification of the Electricity Association (Electricity Association, Technical Specification 43-88,1987). According to these standards, a total dry salt retention of 10kg/m^3 was required for each pole. Figure 2.10 therefore shows Sitka spruce to meet this regulation only in the outer 10mm of sapwood, whereas the other three species are in excess of 10kg/m^3 of CCA to depths of 35mm (Norway spruce), 55mm (Scots pine) and 80mm (Corsican pine). This variability in preservative levels in the outer sapwood is obviously very

important when considering the suitability of different species for use as poles. The inclusion in the standard of both a minimum CCA penetration and retention would highlight treatment problems observed in species such as Sitka spruce and thereby ensure that such impermeable wood species would not satisfy the more rigorous criteria in any revised standard

Radial patterns of total CCA salt content in all four wood species (Figure 2.10) show a concentration gradient which decreases from a maximum at outer pole surfaces to a minimum at pole centres. This type of distribution pattern was previously found in timber treated by the empty cell process (Arsenault, 1975; Cokley and Smith, unpublished report cited by Norton, 1979) and the pressure Boucherie process (Johnstone and Blau, 1970). A process using a combination of these two methods, such as the high pressure sap-displacement (HPSD) process used in this study might therefore reasonably be expected to produce similar radial preservative gradients. This was indeed found in the sap-displacement treated poles in this study (Figure 2.10).

On examination of the radial distribution of the individual preservative components, all three were found to be higher on pole surfaces compared with pole centres (Figures 2.6 - 2.9). Chromium and arsenic generally showed concentration gradients decreasing from pole surfaces to pole centres, however, in Corsican pine, Scots pine and Norway spruce, copper showed an intermediate peak in concentration at varying distances from pole surfaces (Figures 2.6 - 2.8). The presence of this concentration peak suggested possible disproportionation of the preservative components during treatment and was confirmed by calculation of

salt ratios across the radial profiles of cores from the four wood species (Table 2.3). Salt ratios deviated from the nominal value of 35:45:20 (copper:chromium:arsenic) with the proportion of copper increasing steadily towards pole centres of all four wood species.

Disproportionation of CCA elements was reported in an early paper by Dahlgren (1972) and was thought to result from ion-exchange fixation of copper, adsorption of chromic acid and early precipitation fixation during the initial fixation reactions of CCA with wood. The degree of disproportionation was also reported to vary with depth of penetration (Dahlgren, 1972), which may explain the increasing proportion of copper found at greater radial depths in this present study (Table 2.3). Jansen et al., 1985) suggested differences in the rate of fixation of the three preservative elements, with chromium fixing first followed by arsenic and then copper. Chromium and arsenic were thought to exist mainly as chromium arsenates. Rapid fixation of chromium and arsenic would cause disproportionation of the preservative, resulting in an excess of copper and may explain the imbalances of copper, chromium and arsenic observed in the field poles.

The formation of insoluble sludges in CCA preservatives has been well documented (Mason, 1982; Pizzi et al., 1984; Mutandadzi and Evans, 1990) and is thought to result from reactions with acid soluble wood components. The extent of sludge formation has been shown to vary depending on the pH, concentration and formulation of the preservative solution (Mason, 1982; Mutandadzi and Evans, 1990). Analysis of these

sludges has shown them to contain very high levels of arsenic, slightly lower levels of chromium and minimal amounts of copper (Mutandadzi and Evans, 1990). Sludge formation during treatment cycles would therefore be expected to cause imbalances in preservative composition which may then alter final salt balances within the treated wood. In particular, during the sap-displacement process, sap solution extracted from the poles via suction caps is circulated with CCA preservative throughout the 40 hour treatment cycle. Sludge formation may therefore result in an abnormally high proportion of copper within the preservative solution due to precipitation of arsenic and chromium.

This may also account for the proportionally higher levels of copper recorded in poles in this study (Table 2.3) which may be a direct consequence of reduced levels of arsenic and chromium in treatment solutions due to formation of insoluble sludges. If CCA penetration increases with increasing treatment time then this effect will be highlighted at greater radial depths due to the cumulative effect of sludging during the 40 hour cycle. This would indeed explain increasing disproportionation of copper towards pole centres (Table 2.3).

The formation of insoluble sludges with CCA preservatives may also explain the rapid fixation of chromium and arsenic described by Jansen et al (1985). Since sap-diplacement treatment is undertaken on freshly felled timber, the high sap content of the wood may react with preservative components causing the formation of insoluble 'sludges' within the wood. Similar to sludge formation in the bulk solution, these insoluble complexes

within the timber would be composed mainly of arsenic and chromium and would leave a preservative imbalance with proportionally higher levels of copper.

The presence of peaks in copper concentration have also been recorded in poles treated by conventional pressure impregnation processes (Cokley and Smith, unpublished report cited by Norton, 1979; Evans et al., 1987b). The events which lead to the production of copper peaks are not therefore produced solely as a consequence of the high pressure sap-displacement process employed in this study.

Although it is important to determine total salt loading and penetration in treated poles, the importance of retention and distribution of individual preservative components must also be recognised. Copper and arsenic are understood to be the major anti-microbial components of CCA (Wallace, 1968), consequently, levels of these individual elements must be monitored in any study of preservative efficacy. Since decay of CCA-treated material is caused primarily by soft rot organisms at the wood/soil interface it is important that copper and arsenic levels at the pole surfaces should be monitored. Nilsson (1982) emphasised this point by reporting a toxic threshold of 0.2% (w/w) copper for the decay of *Pinus* spp by soft rot fungi. The results of this present study show that, all four species had copper levels in excess of 0.2% at pole surfaces (Figures 2.6 - 2.9) indicating that adequate protection against this form of microbial decay should be, and indeed was, achieved. Closer inspection of copper levels at the surface of Sitka spruce poles shows that initial levels (Evans et al., 1986b, 1987a) were below

the 0.2% toxic threshold, whilst after 1, 2 and 3 years field exposure these values had increased to 0.3 - 0.35% (Figure 2.9). It appears that some migration of CCA components occurred during field exposure and as a consequence, has improved the protection against soft rot decay fungi.

2.4.2. CCA Permanence.

The analytical data from this study indicate that some migration of CCA components occurred during field exposure of poles of all four wood species. Statistical comparison of pre- and post-implantation levels of copper, chromium and arsenic (Table 2.6) showed significantly higher levels of each element at the groundline of poles after field exposure. Migration of CCA components therefore resulted in increased levels at the groundline region thereby conferring additional protection to the area of the poles which is most susceptible to soft rot decay.

It was apparent that CCA movement had occurred mainly during the first year of field exposure. This was concluded from statistical comparison of the data recorded at years 1, 2 and 3, where it was shown that in many cases, particularly Sitka spruce, there was no significant difference in copper, chromium and arsenic levels at the three sampling periods (Table 2.6). In those cases which did show a small, but significant difference between the three sampling times e.g. Norway spruce, it should be pointed out that radial profiles for years 1, 2 and 3 (Figures 2.6 - 2.9) are very similar to each other and are consistently higher than those at year 0.

Migration of CCA components within the poles was confirmed by analysis of cores removed at three heights after four years field exposure (Figs. 2.12 - 2.15). In most instances, groundline levels of copper, chromium and arsenic were significantly higher than those at heights of 3.5 and 6.5m (Table 2.7). Initial sampling at these three heights showed there to be little longitudinal difference in preservative levels (Evans et al., 1987a), proving that migration of CCA components towards the groundline had occurred during field exposure.

A variety of workers have studied the permanence of CCA preservatives in laboratory scale experiments using small wood specimens and severe leaching conditions. In most cases, arsenic was found to be the most readily leached component (Henshaw, 1979; Norton, 1979) and chromium the most leach resistant (Hager, 1969; Rak and Clarke, 1974). A number of factors were found to contribute to the leachability of the components, and included preservative formulation (Fahlstrom et al., 1967; Smith and Williams, 1973), ionic composition (Irvine et al., 1972; Plackett, 1984) and pH (Hager, 1969) of leach water, and drying time after treatment (Hager, 1969).

Although it was reported by Belford (1970) that there was a lack of field studies undertaken on the permanence of salt-type preservatives, some long-term field evaluations have been reported. Softwood poles treated with CCA by the full cell process and exposed to field conditions for up to 17 years showed losses of the preservative to be negligible (Anon., 1957). Arsenault (1975), also confirmed the high level of permanence of CCA within pine poles exposed to service conditions for 32 years,

reporting that no significant loss of any component occurred. The same author did however, record losses of copper and arsenic from below ground regions of 26 year old pine posts, attributing the poor performance to initial under-treatment of the timber. This may be an important consideration in the use of Sitka spruce poles where very low retention and penetration of CCA were achieved (Fig. 2.10). Prolonged field exposure of these poles may result in leaching of preservative components thereby reducing the treatment further. Leaching of CCA components from softwood poles under service conditions was confirmed by Nurmi (1990) with greatest losses of all three components from the groundline region.

Chemical analysis of cores removed from poles in this present study has confirmed migration of copper, chromium and arsenic during field exposure. Migration occurred in a downward direction, resulting in accumulation of the three preservative components in the groundline region. Since the majority of this movement appears to have occurred in the first year of field exposure, it is most likely that active leaching of the preservative had not occurred but that migration of unfixed material upon erection of the poles, was being observed. Although the poles were allowed a four month fixation period, it is possible that a very small proportion of the preservative had remained unfixed. This may indeed be the case if disproportionation of copper, chromium and arsenic had occurred during treatment. Erection of the poles in the field would provide both the effects of gravity and precipitation which may contribute to downward migration of metals in the poles.

A similar study was undertaken on the distribution of creosote in pine poles after 23 years field exposure (Andrews et al., 1955). The authors found significant creosote losses above ground compared with the groundline, and suggested that movement down the poles by the effects of gravity and water leaching would contribute to this result. Accumulation of creosote at the groundline of poles in service for 10 years was also reported by Nurmi (1990). The author suggested a downward migration of creosote to the groundline, where the movement became much slower due to much higher moisture contents and lower temperature. Accumulation of CCA at the groundline in this present stdy may have therefore resulted from similar effects.

A study by Fowlie (unpublished data, 1986) to quantify the volume of water flowing down poles showed that 3.39 gallons per inch of rain could be expected to flow down an average sized pole. Although the sheer volume of rainwater running down treated timber may eventually affect permanence of preservatives, as reported by Evans (1987) for CCA-impregnated pitched roofs, the pH of this rain could also have a great influence on leachability. In recent years, the possible effect of 'acid rain' on CCA-treated timbers has caused increasing concern. Acid rain is generally considered to be rainfall with a pH lower than 5.6, and is caused by the combination of industrial sulphur and nitrogen oxides with atmospheric moisture (Murphy and Dickinson, 1990). The pH of leach water has been shown to affect greatly the leachability of CCA components, particularly copper. Hager (1969) showed increasing copper losses with decreasing pH, and Murphy and Dickinson (1990) reported up to 40 % losses of copper after

leaching in simulated rainfall at pH 3.0. Rainfall collected in the vicinity of the field poles in this present study was found to be near neutral i.e. pH 6.6, and was therefore not thought to cause an increased leaching hazard.

Downward migration of CCA components within the poles also resulted in copper and chromium accumulation at pole surfaces at the groundline region. Figures 2.13 and 2.14 show this effect in Scots pine and Norway spruce poles after four years field exposure. It is likely that unfixed material within the poles has migrated towards the groundline where, on increased exposure periods (four years), preservative components have migrated towards pole surfaces and may eventually leach into the surrounding soil.

Redistribution of CCA components (Greaves, 1974) and accumulation of copper and chromium at outer wood surfaces (Drysdale, 1983) have been found during leaching studies on small wood samples, and have been suggested as a possible cause of reduced moisture uptake during soil burial (Green et al., 1989). There is however, a lack of similar information on large dimension timbers under service conditions. Surface accumulation of copper and chromium, and the apparent radial movement of the peak in copper concentration, which were found in this present study, do however confirm that redistribution of CCA components can occur during field exposure of treated poles.

Analysis of CCA levels in soil adjacent to the poles showed increased levels of copper and chromium relative to soil background concentrations, indicating that some leaching of the preservative elements had occurred (Hainey et al., 1989).

Although migration of arsenic had occurred within the poles, no significant increase in arsenic levels was recorded in soil adjacent to the poles. Arsenic is however, reported to be the most readily leached component from CCA treated timber (Norton, 1979; Henshaw, 1979; Evans, 1987; Nurmi, 1990) and it is possible that it may have diffused away from the poles due to its higher mobility in soil (Jacobs et al., 1970) than that of the other preservative elements, particularly copper (Leeper, 1978).

Although Sitka spruce possessed significantly lower retention and penetration of CCA (Fig. 2.10), significantly higher levels of chromium were found in soil adjacent to poles of this species compared with the other three species. This effect has been found previously in laboratory scale experiments using small woodblocks (Fahlstrom et al., 1967; Dahlgren, 1975a; Briscoe, 1987) confirming that the rate of leaching is greater at lower preservative retentions. Arsenault (1975) reported a similar effect in 26 year old pine posts, where losses of copper and arsenic were consistent with poor initial treatment of the timber.

Though leaching of the preservative components to the surrounding soil occurred, it is important to note that in comparison to the total loading of CCA in the poles, the amount of CCA leached was minimal. Treatment of the poles remained at very high levels, with no apparent reduction during the field exposure period, and the small increases in copper and chromium in soil adjacent to the poles were not considered as potential environmental hazards.

2.4.3. Factors Affecting Fungal Colonisation.

Radial moisture profiles recorded for the field poles (Figure 2.16) show pine species to be much wetter than spruce species, particularly at the groundline. Moisture conditions within the poles obviously reflect the permeability of the wood species, consequently, low moisture levels are observed in spruce species, particularly Sitka spruce. Low moisture levels in the spruce species correlate well with lower retention and penetration of CCA preservative recorded in these poles, and are due to the anatomical reasons discussed earlier (Liese and Bauch, 1967). In all four wood species however, moisture levels are at, or above, fibre saturation point (~30% moisture content) to radial depths of up to 100mm. Moisture conditions within the poles are therefore adequate for fungal colonisation.

Groundline regions of the poles of each wood species were much wetter than at a height of 1m, particularly in the more permeable pine species. High moisture contents were expected at the groundline regions due to moisture uptake from the surrounding soil, however, it has been suggested by Baines and Levy (1979) and Baines (1983) that moisture from wet below ground regions may be transported to drier above ground zones as a result of a wick effect. Baines (1983) demonstrated this effect during soil burial of small Scots pine stakes, reporting that this water movement may also cause translocation of soluble nutrients to upper regions of the stakes. This effect was however, discounted by Becker and Zycha (1958) during a study of poles under service conditions.

The average annual rainfall in the vicinity of the poles during their first four years of exposure was 660mm (Edinburgh Climate Office), and Fowlie (unpublished data, 1986) reported a volume of 3.39 gallons per inch of rain to flow down an average 10m pole. An annual average of 89.5 gallons of water could therefore be expected to flow down each pole within the field site, causing moisture increases in both the wood and soil. Groundline moisture levels in the poles would therefore be maintained at a high level due to the equilibrium between wood and soil moisture. Checks in this region would also tend to close as a result of high moisture and may therefore further trap water in the poles and reduce evaporation.

Radial profiles of moisture content near the groundline show reduced levels at pole surfaces, particularly in the pines, which may be explained simply by the effect of evaporation at pole surfaces. CCA-treated wood has however, been reported to show lower moisture uptakes than untreated wood (Gray, 1986; Pizzi and Conradie, 1986; Green et al., 1989) therefore the very high CCA contents at pole surfaces may show lower moisture uptakes than inner regions where lower CCA retentions were recorded.

Differences in moisture contents between pine and spruce poles are also reflected in the frequency and severity of checks recorded in the area 1m above groundline. On examination of the extent of checking (Table 2.9), it was found that checks were larger and more numerous in the spruces, particularly Sitka spruce, probably as a direct consequence of reduced moisture contents of these species. It should be noted that poles were examined for the presence of checks during a very wet period when

checking would be expected to be at its lowest, however, Sitka spruce still showed the presence of checks which were deep enough to breach the band of preservative protection, therefore providing a route of entry to untreated heartwood for decay fungi. Evans et al (1991) reported check measurements for the same poles during a drier period and showed much more severe checking. Spruces were again, reported to be affected more seriously than the pines, however, Sitka spruce was the only species to show checks extending into the untreated heartwood. If Sitka spruce poles are to be considered for commercial use, methods should therefore be employed to reduce the extent of checking. Methods currently being tested include kerfing (Ruddick, 1988; Morrell, 1990), and the addition of polyethylene glycol (Trumble and Messina, 1986) and water repellant emulsions (Warburton etal., 1991) to the treatment system.

It is important to note that all poles possessed moisture contents above fibre saturation point, and that in some cases, especially Sitka spruce, extensive checking provided an avenue of entry for fungal spores to untreated heartwood regions. Isolation studies from the poles (Table 2.10) indicated colonisation of both CCA-treated and untreated regions of poles of all four wood species, by a variety of fungal species. In most instances, the organisms were non-decay mould fungi, however, white rot decay fungi were isolated from internal regions of two of the five Sitka spruce poles after only four years field exposure. This surprisingly early colonisation of the Sitka spruce pole interiors by decay fungi is almost certainly associated with ease of entry of the fungus as a conseqence of the narrow band of

preservative penetration and the extensive checking in this species.

It is generally believed that softwood species are more susceptible to decay by brown rot fungi, whilst hardwoods are more susceptible to white rot fungi (Nilsson and Daniel, 1987). Possible reasons for such host preferences include the greater ability of brown rot fungi to degrade softwood hemicelluloses (Lewis, 1976) and the limiting effect of high lignin contents of softwoods on degrade by white rot fungi (Highley, 1976). Differences in lignin type between softwoods and hardwoods have also been linked to preferential decay by brown and white rot fungi (Highley, 1987). White rot decay of CCA-treated softwoods has however, been reported during a survey of decay types in pine posts (Nilsson, 1984; Drysdale et al., 1986). Although white rot was detected in many of the posts, and was considered an important decay type, decay was restricted to the outer surfaces and therefore not regarded as a likely cause of post failure (Nilsson, 1984; Drysdale et al, 1986).

The major decay type in salt treated softwoods is widely reported to be soft rot (Henningsson and Nilsson, 1976; Schmidt and Jacobsson, 1976; Drysdale et al.; 1986), however, visual signs of soft rot were not evident in this study after four years pole exposure. Many of the mould fungi isolated from the poles belong to genera which have previously been reported to be potential causes of soft rot decay e.g. *Alternaria* spp., *Fusarium* spp., *Cephalosporium* spp. (Drysdale et al., 1986; Wang and Zabel, 1990), however others, including *Penicillium* spp. and *Hormoconis* spp. were found to lack wood degrading activity

(Henningsson and Nilsson, 1976). The presence of some potential soft rot organisms may indicate that soft rot may develop in the field poles, however, the very high CCA levels presently recorded in the poles should give adequate protection against this type of decay.

Results from field testing of three of the wood species CCA-treated by sap-displacement, have therefore indicated that, at present, excellent protection against decay is being provided. The early colonisation of Sitka spruce poles by basidiomycete decay fungi, as a result of low preservative penetration and extensive checking, does however, suggest that this species may not be suitable for long term field service.

CHAPTER 3

EXPOSURE OF POLE SECTIONS TO ACCELERATED DECAY CONDITIONS

3.1. INTRODUCTION.

In the development of any new wood preservative or method of treatment, thorough testing of the performance of the treated product must be undertaken prior to its commercial acceptance. The most accurate means of testing treated timber is to expose it under natural field conditions and assess its performance at regular intervals to determine the average service life. Such testing may however, require twenty or more years of field exposure to achieve satisfactory results (Johnson et al., 1982) and is therefore not practical due largely to constraints of time and expense.

In an attempt to accelerate the testing of treated wood products, a variety of laboratory based systems have been developed over the years, exposing small wood specimens to moist, warm soil for periods of up to 3-4 months. Although these test procedures are considered to be invaluable in routine screening procedures, and for establishing relative performances of preservatives, they have been widely criticised for their inability to predict 'in service' field performance (Gersonde and Becker, 1958; Anon., 1978).

The limitations of the two types of testing systems mentioned above, have encouraged a number of workers to develop intermediate systems in an attempt to bridge the gap between the extremes of field testing and small scale laboratory testing (Gersonde and Becker, 1958; Deppe and Gersonde, 1977; Anon., 1978; Johnson et al., 1982; Greaves et al., 1982; Vinden et al., 1982). These systems, initially called 'fungal cellars' (Gersonde

and Becker, 1958), employ the accelerated decay conditions of laboratory test systems but can accomodate larger, more representative wood specimens which bear closer resemblance to full size service timbers.

Fungal cellars were first developed for the testing of treated timbers by workers studying the decay of building materials (Gersonde and Becker, 1958; Deppe and Gersonde, 1977). In these early studies, wood specimens were exposed to basidiomycete fungi cultured in sterilised soil within a controlled environment. The use of fungal monocultures has also been used recently in the testing of building timbers treated with a variety of preservatives against the dry rot fungus *Serpula lacrymans* (Doi, 1989). A small-scale version of the fungal cellar was also developed for the exposure of treated timbers to a variety of basidiomycetes, including *Gloeophyllum trabeum* (Hansen, 1973).

In 1978, the Forest Research Institute (FRI), New Zealand, introduced a facility for the accelerated testing of preservative treated timber when exposed to the natural soil microflora (Anon., 1978). This system was soon to become the basis of a number of fungal cellars developed in a variety of other countries. The term 'fungal cellar' was retained by FRI (Hedley, 1980, 1983, 1986) but Johnson et al (1982) suggested that the term 'Accelerated Field Simulator' (AFS) was more appropriate since their system was designed to simulate field conditions while accelerating the rate of biodeterioration which occurs in the field. The studies by Johnson et al (1982) included the exposure of timber to a range of natural soil microflora and

fauna, including a species of termite, therefore the term 'fungal cellar' no longer accurately described such a facility. An accelerated testing facility developed in the UK (Vinden et al., 1982, 1983a and b) used the term 'soil-beds' to describe the containers of unsterile soil in which treated samples were incubated, but still used the general term of 'fungal cellar' for the controlled room in which the soil-beds were placed.

The exposure of sap-displaced CCA-treated softwood poles to field conditions (Chapter 2) has highlighted the problem of time limitation which is often encountered during these long-term testing procedures. After four years exposure, information on the comparative performances of the four wood species is limited, with the isolation of basidiomycete fungi from two Sitka spruce poles providing the only indication of decay development. As a consequence, a laboratory-based facility was designed and developed in a bid to accelerate decay in the treated timbers and thereby provide information on the comparative performances of the four timber species within the time period of the project.

The facility was designed with close reference to previously reported systems, incorporating favourable aspects of different systems whilst maintaining construction costs within a reasonable budget. Temperature and humidity conditions within the facility were set at the same levels as the original FRI fungal cellar (Anon., 1978), however preparation of the soil-beds and control of environmental conditions were more similar to those reported by Vinden et al (1982).

Much comment has arisen over the appropriateness of terms used to describe previous systems (Johnson et al., 1982). Although criticism of the term 'fungal cellar' by Johnson et al (1982) is justified, the new name of 'accelerated field simulator', as introduced by these workers, may also be regarded as inappropriate. While conditions within these systems are known to accelerate decay, as reported by Hedley (1983) who found that treated samples incubated in a fungal cellar generally decayed 7-12 times faster than similarly treated samples exposed to field conditions, they do not totally simulate the natural conditions present in the field. In addition to the lack of rainwater and natural weathering effects on the timber, the high temperature and humidity within these systems will most likely alter the microbial ecology of the soil. Studies similar to those undertaken by Clubbe (1983) are required to determine if the ecology of decay within these systems accurately represent that found under field conditions. With regard to the above criticisms, it was decided that the term 'Accelerated Decay System' most accurately described the facility developed for this project, since the system neither involved exposure to fungal organisms alone, nor simulated natural field exposure conditions.

For the purposes of this study, the accelerated decay system is required to replicate all of the fungal decay hazards to which field poles are exposed, namely soft rot and basidiomycete decay. This requires the wood specimens to be exposed to both natural soil microflora and artificial inoculation by basidiomycetes, consequently the system must possess elements of previous systems using natural soil conditions (Anon., 1978; Johnson et al., 1982)

and fungal monocultures (Greaves et al., 1982; Doi, 1989).

Wood sample design must again reflect, as accurately as possible, the decay hazard to which full size poles are exposed. To encompass the physical properties of poles which may affect their susceptibility to decay, the wood sections should be partially treated, preferably by the appropriate commercial treatment process and possess checks which extend to the untreated heartwood core. On exposure of the samples to soil, only the curved tangential surface of the wood should be in direct contact with the soil, as is the case with poles in the the field situation. Each of these factors were taken into consideration during preparation of the test samples, and as a result they are more representative of the commercial product than fully treated sapwood stakes which are commonly used in these test systems (Anon., 1978; Hedley, 1980, 1983, 1986; Vinden et al., 1982, 1983a and b).

Decay assessment of small woodblocks used in laboratory test systems is generally achieved by weight loss studies, however, in the case of larger dimension test samples the development of appropriate test methods must be more diverse. Since the test samples and exposure conditions are designed to 'mimic' the field situation as closely as possible, assessment of decay should include all aspects of the decay hazard. Soft rot and basidiomycete decay should therefore be assessed separately and the position of decay within the pole sections should be accurately recorded i.e. internal decay, surface decay and/or decay along checks. An important part of this project therefore involved the development of different methods for accurately

assessing the extent of decay within the pole samples.

The major objective of this part of the project was therefore to develop an accelerated decay system which could be used to provide a severe decay hazard for exposure of representative samples of Corsican pine, Scots pine, Norway spruce and Sitka spruce poles treated with CCA by the sap-displacement process. The comparative performance of these four species was assessed using various test methods developed for this specific system.

3.2 METHODS.

3.2.1. The Accelerated Decay System.

The facility consisted of a concrete encased, irregularly shaped room of approximately 82m^3 which was sealed from adjacent rooms to enable strict control of the temperature and humidity. The room contained eighteen black polypropylene water tanks (Merlin Ltd., UK), 700mm x 1000mm x 700mm and filled to a depth of 410mm with graded soil material. To encourage drainage of excess water, the lower 110mm consisted of coarse stones and gravel embedded in sand and each tank also contained sixteen drainage holes (10mm in diameter). Immediately above this layer was 110mm of unsieved, stone-free soil which was covered with a layer of 190mm depth of fine soil which had passed through a 2mm sieve. The soil was non-sterile, regularly fertilised, sandy loam, agricultural top soil supplied by the Scottish Crop Research Institute, Invergowrie, Dundee. To maintain high humidity levels within the tanks each soil-bed was covered with a 3mm thick sheet of perspex (750mm x 1050mm) supported on the tanks by strips of PVC foam rubber (600mm and 800mm long respectively). Since the foam strips were not continuous along the entire length and width of the tanks, air was able to circulate over the soil surface. A view of the facility is shown in Figure 3.1.

Throughout the duration of the experiment, the temperature and humidity of the room were monitored every 2-3 days using wet and dry thermometers and established at 26-28.5^{o}C and 75-85%,

respectively. These conditions were maintained with the use of

Figure 3.1. The temperature and humidity controlled room containing individual soil-beds (perspex covers have been removed to allow a better view of pole sections).

two 1.5kW garden glasshouse fan heaters (Autogrow Greenhouse Heater E2R) placed at opposite ends of the room and blowing hot air over trays of water. Humidity was also raised with the aid of an Xpelaire humidifier (model no. EH 10) which was placed in the centre of the room. Under these conditions, the area below the perspex covers in each of the soil tanks were maintained at 26° C and 95-100% relative humidity.

Two different garden moisture meter probes (Camplex plantcare moisture meter, model no. HD 500 M, Bentall Simplex

Ltd., UK, and Rapitest water tester, Wilson Grimes Products, UK) with arbitrary scales (0-5), were calibrated using sieved soil prepared to moisture contents which corresponded to 40, 60, 80 and 100% water holding capacity (WHC). The moisture content of the soil at 100% WHC was established by the method of Savory and Carey (1973), and was then used to determine the moisture contents of the soil at 40, 60 and 80% WHC. The calibrated moisture probes were used to closely monitor the moisture content of the soil within the large tanks which was maintained at 100% WHC by the addition of water if and when it was required (using a watering can with a fine spray attachment). During the setting up and early use of the soil beds it was necessary to add water at regular intervals (every 4-7 days), however, after about 6 weeks of operation a more stable equilibrium was reached and watering was only required approximately every 8-10 weeks.

3.2.2. Monitoring of Soil Decay Potential.

Throughout the duration of the experiment, the decay potential of the soil was monitored by measuring the extent of decay of small lime (*Tilia vulgaris* Hayne) sapwood blocks. Four pre-weighed lime woodblocks (20 x 10 x 5mm) were buried to a depth of 80mm in each of the eighteen soil beds. After a burial period of six weeks the blocks were uplifted and their percentage moisture content and percentage weight loss (both on original dry weight basis) were determined. Woodblocks were buried in the soil beds 1, 5, 16 and 23 months after the initial operation of the decay system.

3.2.3. Preparation of Wood Sections.

10m poles of Corsican pine, Scots pine, Norway spruce and Sitka spruce were treated with a 1.8% CCA Type II preservative solution by pressurised sap-displacement, as described in section 1.5. Control poles were treated by the same sap-displacement process except that water was used instead of the preservative solution. After treatment, the poles were left for approximately six months to allow preservative fixation to occur. Poles were then sawn into segments approximately 250mm in length which in turn were sawn longitudinally to produce quartered pole sections. A representative section is shown in Figure 3.2.

To ensure that only the curved surface of the sections was exposed to the soil, as would be the case with whole poles, the two radial longitudinal faces were sealed with two coats of a styrene resin (Scott Bader Co. Ltd., Northamptonshire, England). In addition, the lower transverse face of each section was also sealed with the resin to prevent excessive water uptake and possible waterlogging of the timber. After coating, a metal wedge was used to carefully open a single natural check in each of the sections. The checks were opened to the depth of the untreated heartwood core (approximately 5mm wide) to simulate the presence of seasoning checks in the field exposed poles which may provide a possible avenue for entry of decay organisms to untreated inner pole regions. The checks were kept open by placing small pieces (10 x 50mm) of 3mm thick perspex into the checks, ~20mm from each end of the sections, as shown in Figure 3.2.

Figure 3.2. Representative CCA-treated pole section exposed in the accelerated decay system.

Preliminary studies (Evans and King, 1985, unpublished report) showed that burial of the end-sealed wood sections in the soil beds resulted in very slow moisture uptake and indicated that they would take an excessively long time to reach moisture contents which were conducive to decay. Consequently, all

sections were wetted to approximately 30% moisture content (w/w on an original dry weight basis) prior to their burial in the soil beds. The moisture contents of several representative sections of each wood species (both treated and controls) were determined by recording their weights before and after drying to constant weight at 50° C. The average moisture contents for each species was taken as representative of all wood sections of that type and used to determine the individual dry weights of each section. The target weight (i.e. weight of section at 30% moisture content) of each section was then calculated and the sections were totally immersed in water and periodically weighed until the target weight was reached.

In order to examine the possible effect of this immersion process on the levels and distribution of the CCA components, a leach experiment was set up as described in section 3.2.12.1.

At this stage of setting up the decay system, two separate experiments were initiated. The final preparations of the wood sections for each of these experiments will be dealt with separately in the following two sections.

3.2.3.1. Soft Rot Test System.

Nine of the previously prepared soil beds were randomly selected for use in this experiment. Immediately after wetting, the CCA-treated and control sections were buried to a depth of 150mm in the soil. Each soil bed contained eight wood sections in total which were spaced at approximately 200mm from each other and at the same distance from the sides of the tank, as shown in

Figure 3.3. Although the sections were selected randomly for emplacement into the individual soil beds, the burial plan ensured that each tank contained two sections of each wood species (not both control sections), each of which would be removed at different sampling times. At least one, and a maximum of two, control sections of any species was present in each soil bed, though if two control sections were present they were never the same species.

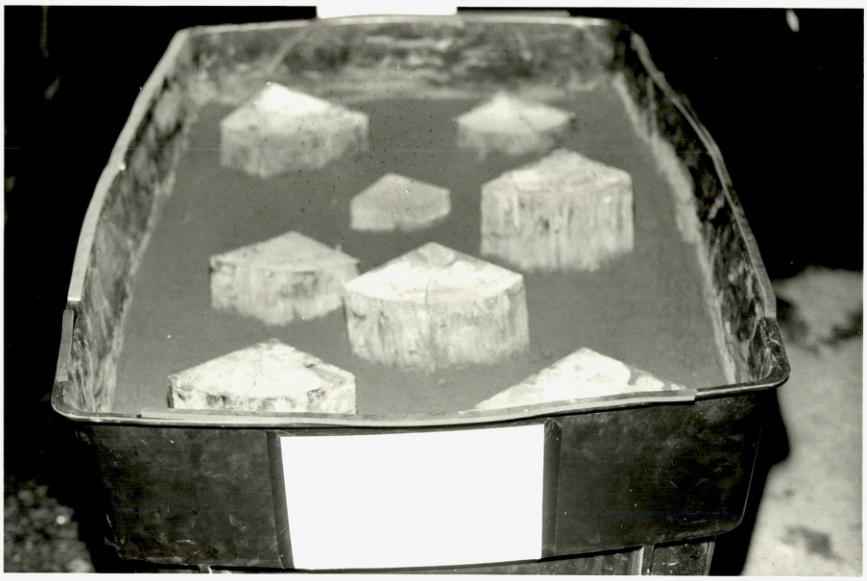


Figure 3.3. Layout of buried pole sections in a soil-bed.

A total of fifteen CCA-treated and three control sections for each wood species (i.e. 72 sections in total) were therefore

buried within the soft rot test system. At sampling times of 12, 18 and 24 months after the initiation of the experiment, five treated and one control section of each wood species were uplifted and examined for development of surface soft rot decay (3.2.5 and 3.2.6), moisture profiles (3.2.7), development of internal decay and decay of their checked surfaces (3.2.8) and permanence of the CCA components (3.2.13).

3.2.3.2. Basidiomycete Test System.

In order to simulate the entry of basidiomycete decay fungi into the checks of poles in service, wood sections were sprayed directly into their open checks with a mixture of the macerated mycelia of the two basidiomycete fungi, *Gloeophyllum trabeum* and *Trametes versicolor*.

Prior to preparation of the fungal spray inoculum, initial testing of the compatibility of a range of brown and white rot organisms was carried out. The test fungi were selected from the wide range of basidiomycetes used in previously reported decay tests of untreated and CCA-treated wood. The following basidiomycetes were tested:-

Gloeophyllum trabeum	(Pers:Fr.)Murr. (BAM Ebw.109)	brown rot producers
Coniophora puteana	(Schum:Fr.) (BAM Ebw.15)	
Neolentinus lepideus	(Fr:Fr.) Redhead and Ginns (BAM Ebw.20)	
Trametes versicolor	(L. ex Fr.) Pilate (FPRL 28B)	white rot producers
Pleurotus ostreatus	(Jacquin ex Fries) Kummer (FPRL 40A)	

Each brown rot organism was tested against each white rot organism by placing agar cores removed from the edges of actively growing cultures of each fungus at opposite sides of petri-dishes containing 3% malt extract agar (Oxoid No. CM59) and 4ppm benomyl. Triplicate plates were set up for each cross and all plates were incubated in the dark at 25° C to allow the two organisms to interact. After extended incubation, the plates were examined for overgrowth or killing of either of the fungi, or for a stalemate reaction where growth of the two fungi stopped at the point of contact i.e. no adverse effect on either fungus. On the basis of the results of such studies *G. trabeum* and *T. versicolor* were selected as the most compatible combination of brown and white rot fungi tested.

Separate liquid cultures of the two fungi were prepared by placing three agar cores of the actively growing organisms onto the surface of petri-dishes containing 15ml of 3% malt extract broth (Oxoid No. CM57) with 4ppm benomyl. The plates were incubated in the dark at 25° C until growth almost covered the surface of the medium. The mycelial mats from duplicate plates were then transferred to a flame-sterilised stainless steel Waring blender, 50ml of sterile distilled water was added and the mycelium macerated for 30 seconds. The macerated mycelia were transferred to separate pre-sterilised aerosol sprays and the two fungi separately sprayed over the surfaces of two plates of 3% malt extract agar. The two sprays were then combined, mixed thoroughly and sprayed over the surfaces of two fresh plates of 3% malt extract agar. All plates were incubated in the dark at 25°C to check the viability of the fungal mycelia within the sprays.

Growth of both organisms occurred in both the individual and mixed mycelial sprays confirming compatibility of the two organisms in spray form. The mixed inoculum was therefore prepared as described above, for inoculation of the wood sections.

When inoculating the sections (immediately after wetting them to 30% moisture content), the spray was directed into the open check. The whole length and depth of the check was sprayed. Due to difficulties in measuring the volume of the inoculum used per section, the rate of spraying was standardised. Viability tests of the sprays during section inoculation were carried out at regular intervals by spraying the surface of 3% malt extract agar plates. Incubation of these plates confirmed viability of both organisms throughout the procedure.

Immediately after inoculation of the wood sections they were buried in the nine remaining soil beds within the decay system, in the same manner as described earlier (3.2.3.1). Identical numbers of controls and treated sections of each species were prepared and allocated random burial positions as described in 3.2.3.1.

In view of the heavy artificial inoculum of basidiomycetes in this experiment, sections were sampled 6, 12 and 18 months after burial. At each sampling time, five CCA-treated and one control section of each wood species were uplifted and examined for development of surface soft rot decay (3.2.5 and 3.2.6), moisture profiles (3.2.7), development of internal decay and decay of their checked surfaces (3.2.8) and presence of basidiomycete decay fungi (3.2.9).

3.2.4. Dehydrogenase Assay of Soil.

Immediately prior to removal of the wood sections at each sampling time, small soil samples were removed from the soil beds for analysis by a dehydrogenase assay to give an indirect measure of soil microbial activity.

Soil samples were removed from the 5mm adjacent to the surface of the wood sections using an extractor which consisted of two closely fitting U-shaped pieces of metal (5 x 10 x 90mm). Further samples were also removed at a distance of 100mm from the curved surface of the wood sections to give a measure of background levels of the three metals. In the case of CCA-treated sections, the extractor was used to remove five samples at equal distances around the surface of each section at both sampling locations i.e. surface and 100mm. The five samples from each position were then combined and mixed thoroughly before the assay. However, since there was only one control pole section for each wood species, the five samples from around the surface of the section were analysed separately to provide replicate samples. This sampling procedure for control sections was started at the 12 month sampling time. At the 6 month sampling time, the five samples were combined, and therefore only a single measurement is available for each control section.

The dehydrogenase assay used was as described by Mowe (1983), which was a modification of the method of Casida et al (1964). Approximately 2g of soil from each sample was weighed, dried at $103 \pm 2^{\circ}C$ and re-weighed. The moisture content of the soil (on a dry weight basis) was then calculated. A further 2g (wet

weight) of soil was weighed accurately and transferred to a screw-capped glass tube containing 15mg calcium carbonate. After thorough mixing, the material was saturated with 2ml of a 0.75% w/v aqueous solution of 2,3,5,-triphenyltetrazolium chloride (TTC) and mixed thoroughly on a vortex shaker. The tubes were sealed and incubated in the dark at 30°C for 24 hours. A reagent blank of 15mg calcium carbonate and 2ml of 0.75% w/v TTC solution was also incubated.

After incubation, 5ml methanol was added to each tube, mixed, and the heavier solids allowed to settle to the bottom of the tubes. The liquid was decanted into centrifuge tubes and the remaining solids rinsed with a further 3ml methanol. After decanting the liquid into the same centrifuge tube, the final 10ml was centrifuged at 4000 rpm for 10 mins to separate the lighter soil particles. About 5ml of the clear liquid was transferred to a glass cuvette and the absorbance of the red-coloured 2,3,5-triphenyltetrazolium formazan (TTF) determined spectrophotometrically (LKB Ultrospec 4050) at 485nm. A calibration curve of the product (TTF in methanol) was constructed by measuring the absorbances at 485nm of ten standard solutions containing 0.002 to 0.020 umol/ml TTF. A separate calibration curve was constructed each time the absorbance of experimental solutions were measured.

The concentration of TTF (umol/ml) in each test solution was determined by reference to the calibration curve. The weight of soil assayed was corrected to a dry weight using the previously calculated moisture content value, after which the level of dehydrogenase activity was expressed in umol product formed (TTF)

per gram of soil per minute. A typical calibration curve and specimen calculation are given in Appendix V.

Statistical analysis of the data was undertaken by analysis of variance to determine if significant differences existed between (i) the two test systems (i.e. soft rot and basidiomycete test systems), (ii) CCA-treated and untreated control sections, (iii) the four wood species, and (iv) the two sampling positions (i.e. adjacent to the wood surface and at a distance of 100mm). Analysis of variance was also employed to examine the effect of soil burial time on dehydrogenase activity at the surface of untreated control wood sections.

3.2.5. Measurement of Surface Decay using Pilodyn.

Immediately after removal from the soil beds, adhering soil was removed and sections were tested for surface softening using a pilodyn with an impact energy of 2 Joules (Cobra (Wood Treatment) Ltd., Brighton, UK).

A template grid (300 x 300mm) consisting of 40 x 40mm squares was placed over the curved surface of each section and the pilodyn measurement (depth of pilodyn needle penetration in mm) was recorded at the centre of each square. Pilodyn measurements were separately recorded both above and below ground regions of the wood sections.

The wood sections were then split open along their check and the template placed over the newly exposed checked faces. Pilodyn measurements were again recorded at the centre of each square of the template.

Unburied sections were also tested in the above manner, with five CCA-treated and two control sections of each wood species tested on their curved and checked surfaces after wetting to 30% moisture content.

3.2.6. Measurement of Soft Rot by Microscopic Analysis.

In addition to the measurement of surface decay (soft rot) by pilodyn, a semi-quantitative method for measuring both the severity and depth of penetration of soft rot was employed. The method was a modification of the technique reported by Anagnost (1987). At the two positions on the curved surface which had previously shown the highest pilodyn measurements, small, thin wood samples (5 x 5 x 1mm, approx.) were removed at increasing depths (every 2, 4 or 8mm, depending on extent of decay) from the wood surface. The wood was fiberised using a modified version of the method described by Franklin (1946). The wood was boiled for 1 hour in 5ml of a 50/50 mixture of glacial acetic acid (17.4M) and hydrogen peroxide (100 volumes) until the individual wood fibres separated. After mixing on a vortex shaker, a small random sample of the fibres was examined microscopically (x 150 magnification) under polarised light. Under these conditions the wood cell walls appeared white, whilst the characteristic soft rot cavities appeared black.

For each of the samples examined, twenty individual fibres were randomly selected and the extent of soft rot cavitation in each was estimated. Four categories were used to record the severity of soft rot decay in each fibre as follows:-

0 - no soft rot cavities.

1 - less than 50% of cell wall covered with cavities.

2 - greater than 50% but less than 100% of cell wall covered with cavities.

3 - cell wall surface totally covered with large coalesced cavities or showing signs of splitting.

A 'soft rot decay index' value was established for each sample by the addition of the scored results for the twenty fibres. Values therefore ranged from 0, where no cavities were observed, to 60, where each of the twenty fibres examined showed total degradation by soft rot cavities.

Visual examination of the checked surfaces of some CCA-treated and control sections showed grey/black discolouration of the wood with associated surface softening. To check if this was soft rot decay, small wood samples were examined microscopically as described above, and their soft rot decay index determined. Depth of penetration of decay on the CCA-treated sections was determined by measuring the soft rot decay index at increasing depths of 2mm from the checked surface.

Sampling and analysis of soft rot decay of checked surfaces was only carried out on wood sections exposed in the soft rot test system, and was not continued on control sections beyond the 6 month sampling time due to extensive decay in the samples at that period.

3.2.7. Measurement of Moisture Profiles.

Wood sections uplifted from the two test systems at each sampling time were tested to determine their radial moisture profiles. The wood sections were split open along their check to produce two halves. A 5mm thick slice was removed from a position 50mm below groundline of one half of each section (Figure 3.4). Radial samples (5 x 5 x 80mm) were then removed from both the checked surface and internal region of this slice (Figure 3.4) and cut into segments according to the plan in Figure 3.5. Each individual segment was weighed, oven-dried at 103±2°C and re-weighed. Percentage moisture content was then determined on a final dry weight basis. Samples were stored for later analysis of their copper, chromium and arsenic content, as described in section 3.2.12.2.

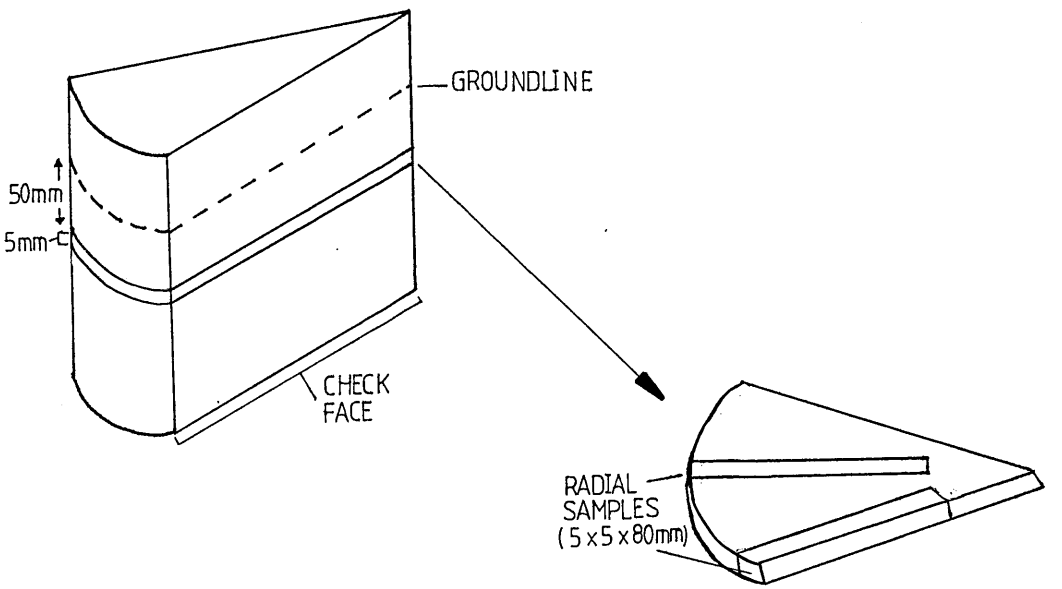


Figure 3.4. Removal of radial wood samples from pole sections for moisture and CCA determinations.

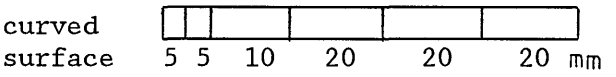


Figure 3.5. Sectioning pattern of radial wood samples for determination of moisture profiles.

3.2.8. Decay of Checked Surface and Internal Cross Section.

A visual estimation of the extent of surface decay of the checked faces was recorded for each wood section removed from both the soft rot and basidiomycete test systems.

After splitting of the wood sections along their checks, the two checked surfaces were examined and the decayed area was recorded as a percentage of the total surface area. The extent of decay was categorised as follows:-

0 - no surface decay

1 - 10% of surface area covered by decay

2 - 20% of surface area covered by decay

'

'

9 - 90% of surface area covered by decay.

10 - wood surface totally covered by decay (100%)

Decay was recorded as surface discolouration and softening, and CCA-treated and untreated regions of the wood sections were assessed separately.

The newly exposed transverse surfaces (cross-section) of each wood section at 50mm below groundline (both halves of each section were cut as shown in Figure 3.4) were also examined. Internal decay was again recorded by estimating the percentage of the cross-sectional area showing visible signs of decay.

A photographic record of the checked and cross-sectional surfaces of each section was also taken at each sampling time.

3.2.9. Isolation of Fungal Colonisers.

At the 6 month sampling period, a detailed isolation regime was employed in an attempt to isolate basidiomycete decay fungi from the wood sections. 5mm thick slices were removed from positions at the groundline and 50mm below groundline of one half of each wood section removed from the basidiomycete test system, as shown in Figure 3.6. These slices were cut into 5mm blocks (see Figure 3.6) then, using a sterile scalpel, fine wood slivers were removed from the centre of these blocks and pushed to half their depth into 3% malt extract agar plates. The agar contained 4ppm benomyl and 0.1% streptomycin sulphate to reduce the growth of moulds and bacteria, respectively. The plates were incubated in the dark at 25°C and pure cultures of basidiomycete organisms were prepared by subculturing the isolates. Although mould growth was discouraged by the presence of benomyl, growth of some deuteromycetes was observed. Pure cultures of these organisms were also prepared.

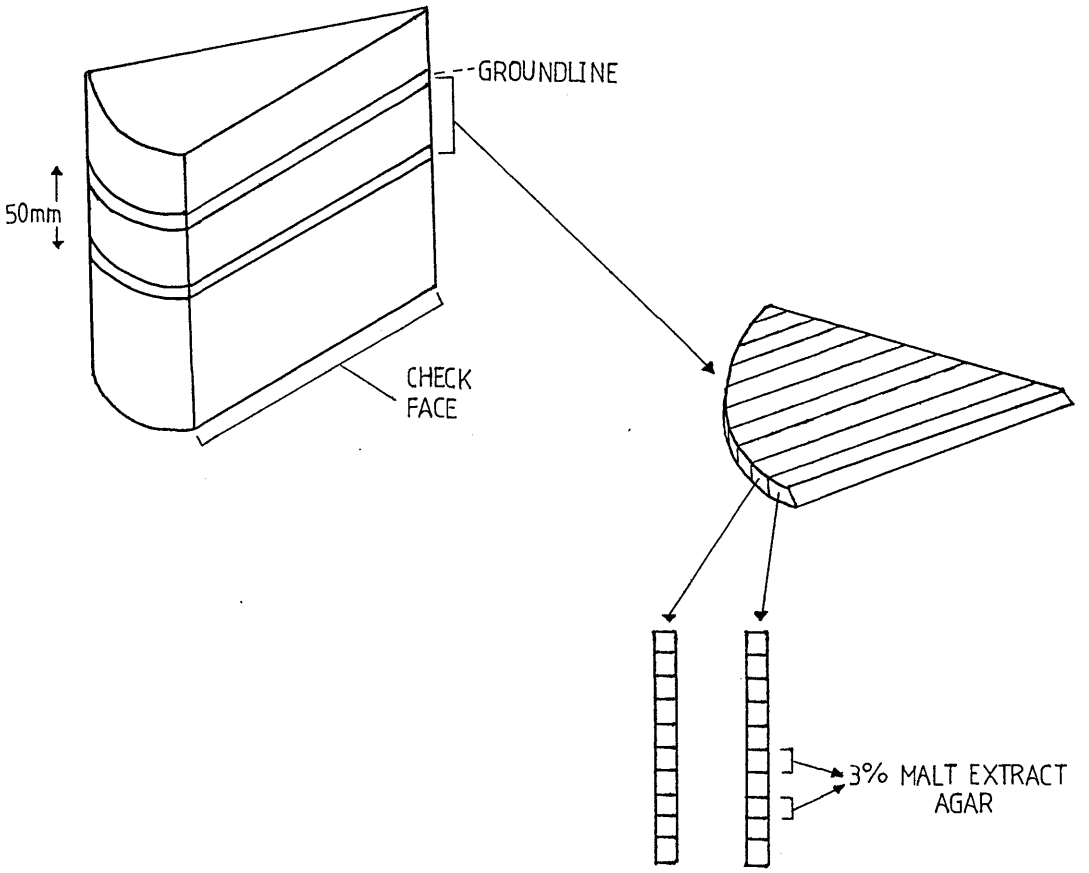


Figure 3.6. Sectioning of pole sections for basidiomycete isolation.

Although a few positive basidiomycete isolations were obtained using this technique, it was obvious that regions of the sections where visual signs of decay were evident, were not being included in the sampling regime since only two pre-determined sampling heights were employed. Consequently, at the 12 month sampling period a different technique was employed. On surface examination of the wood sections from both test systems, all locations showing brown/orange surface discolouration were sampled. At the edge of these discoloured regions, small wood slivers (5-10mm in length) were removed with a sterile scalpel

and pushed to half their depth into 3% malt extract agar plates containing 4ppm benomyl and 0.1% streptomycin sulphate. Pure cultures of basidiomycete organisms were prepared by subculturing the isolates.

Areas showing grey/black discolouration with associated surface softening were also sampled for isolations, in an identical manner to the above. Since it was expected that these regions may be colonised by deuteromycetes, the wood slivers were placed into 3% malt extract agar which contained 0.1% streptomycin sulphate only.

3.2.10. Identification of Fungal Colonisers.

Many of the mould fungi were identified by examining their cultural and microscopic characteristics and comparing them with a key devised by Barnett (1955). Unidentified isolates were sent to CAB International, Mycological Institute, Surrey for positive identification.

Microscopic examination of some isolates confirmed them as basidiomycetes by the presence of clamp connections, however, identification of basidiomycetes proved more difficult due to their lack of characteristic asexual reproductive structures as seen in the moulds. A technique researched at this laboratory for identification of wood inhabiting basidiomycetes (Vigrow et al., 1989), using sodium dodecyl sulphate - polyacrylamide gel electrophoresis (SDS-PAGE) for 'fingerprinting' wood inhabiting fungi was subsequently employed. This technique was used to compare the molecular profiles of isolates from the wood sections

with those of the *G. trabeum* and *T. versicolor* strains used to inoculate sections.

3.2.10.1. SDS-PAGE Analysis of Basidiomycete Isolates.

Preparation of Mycelial Extracts.

Liquid cultures of isolates from wood sections and of *G. trabeum* (Pers:Fr.) Murr (B.A.M. Ebw 109) and *T. versicolor* (L. ex Fr.) Pilate (F.P.R.L. 28B) were prepared by placing three agar cores of the actively growing mycelia on the surface of petri-dishes containing 15ml of 5% malt extract broth. The plates were incubated in the dark at 25°C until growth covered ~75% of the media surface. The original cores were removed from the mycelial mats which were then filtered under vacuum and washed three times with ultra-pure water to remove media components. The filtered material was transferred to round-bottom flasks, freeze-dried and stored at -20°C until analysis.

Prior to gel electrophoresis, the samples were diluted to a concentration of 6.25mg/ml with phosphate buffered saline (PBS,pH 7.4) by grinding the sample with the required volume (16ul of PBS per 0.1mg mycelial extract) using a mortar and pestle. Once a fine slurry had been produced, the material was transferred to a 1.5ml eppendorf tube and boiling mix (see Appendix VI) added at a ratio of 8ul per 0.1mg mycelial extract. The sample was thoroughly mixed and stored at -20°C awaiting electrophoresis.

Before loading the samples onto the gels, they were thawed, heated to 100°C for 3 minutes and centrifuged at 13000 rpm for 10

minutes at room temperature.

Gel Electrophoresis.

The mycelial extracts were analysed by SDS-PAGE using the method of Laemmli (1970) as modified by Marsden et al (1978). 20ul samples of the mycelial extracts were applied to the wells of a 5-15% gradient gel prepared with ultra-pure water as described by Marsden et al (1978). Samples were electrophoresed for 4 hours at 35 mA/gel at 4°C on an LKB 2001 vertical electrophoresis unit.

Silver Staining.

After electrophoresis, the gels were fixed overnight in a solution containing 0.5ml formaldehyde (37% solution) per litre of methanol/acetic acid (50/12) and stained according to the method of Blum et al (1987). This silver staining method consisted of pretreatment with sodium thiosulphate, impregnation with silver nitrate and developing with a solution containing sodium carbonate, formaldehyde and sodium thiosulphate. All solutions were prepared with ultra-pure water and are detailed in Appendix VI.

3.2.11. Cross-reactivity Studies of Basidiomycetes with Mould Isolates.

To establish whether moulds isolated from the wood sections had any effect on growth of the two basidiomycetes contained in spray inoculum, cross-reactivity studies were undertaken.

Each mould isolate recovered from the sections (subsequently identified as *Trichoderma* spp., *Graphium* spp., *Penicillium* spp., *Aspergillus* spp., *Trichurus* spp., *Fusarium* spp., *Gliocladium* spp., *Sporotrichum* spp. and *Byssochlamys nivea*. Westling), was tested against *G. trabeum* (Pers:Fr) Murr (B.A.M. Ebw 109) and *T. versicolor* (L. ex Fr.) Pilate (B.A.M. Ebw 28B). The tests were set up by placing cores removed from the edges of actively growing cultures of each fungus at opposite sides of plates of 3% malt extract agar. Sporulating species were streak inoculated over half of the plate surface. Due to large variations in the growth rates of the test fungi, the slowest growing organism of each cross was inoculated before the faster growing organism to ensure that contact was made near the centre of the plates. Duplicate plates were set up for each cross and all plates were incubated at 25°C. The outcome of the interaction between the two fungi were recorded as either overgrowth, killing or stalemate, as described in section 3.2.3.2.

3.2.12. CCA-Analysis of Wood Sections.

3.2.12.1. Effect of Wetting Wood Sections Prior to Soil Burial.

As mentioned previously, each wood section was wetted to 30% moisture content prior to burial in the accelerated decay system (section 3.2.3). An experiment was set up to check if this procedure had any effect on the levels and distribution of CCA within the sections.

Four sections of each wood species were prepared in exactly the same manner as before i.e. quarter pole sections cut, resin-coated and checks opened (see section 3.2.3). A 5mm thick slice was removed from the top of each of these sections and radial samples (5 x 5 x 80mm) cut from the checked and internal regions similar to that shown in Figure 3.4. Each pole section was then wetted to 30% moisture content by soaking in a known volume of water (3.5 - 5 litres) in separate vessels. After wetting, a 5mm thick slice was removed 50mm from the top of each section and radial samples cut as before i.e. from checked and internal regions. Each radial sample (removed before and after wetting to 30% moisture content) was sectioned according to the plan in Figure 3.6 and CCA extractions and analysis than carried out according to the methods described in sections 2.2.2.2 and 2.2.2.3, respectively.

The copper, chromium and arsenic content of the water used to soak each section was then determined using the standard additions technique described in section 2.2.4.3.

3.2.12.2. Effect of Soil Burial on CCA Levels and Distribution.

To measure changes in preservative levels and distribution which may have occurred during soil burial of the wood sections, copper, chromium and arsenic contents of radial samples prior to soil burial and after 24 months soil burial were determined.

Radial wood samples (5 x 5 x 80mm) were removed from the checked and internal regions (see Figure 3.4) of five unburied wood sections of each species which had been wetted to 30%

moisture content. CCA analysis of samples after 24 months soil burial was undertaken on radial samples previously removed from wood sections for the measurement of moisture profiles (section 3.2.7). Each radial sample was sectioned according to the plan in Figure 3.5, and CCA extraction and analysis was carried out on each small section according to the methods described in sections 2.2.2.2 and 2.2.2.3, respectively.

3.2.12.3. CCA Analysis of Decayed Regions.

Since basidiomycete decay was initiated at the border of untreated and CCA-treated material, decayed regions were analysed by AAS to determine if decay did actually occur in the presence of CCA. Radial samples (5 x 5 x 80mm) which were previously removed from CCA-treated sections of each wood species for moisture determinations (section 3.2.7) were examined for the presence of decay pockets. Where decay was present, the 10mm immediately before the decay i.e. towards the wood outer surface, and the following 10mm i.e. decayed region, were removed and their copper, chromium and arsenic contents determined. CCA was extracted from the wood and analysed according to the methods described in sections 2.2.2.2 and 2.2.2.3, respectively.

3.2.13. CCA-Analysis of Soil.

To determine whether preservative components had leached from the wood to surrounding soil, soil was sampled at each uplift time and the copper, chromium and arsenic contents

determined.

Soil was sampled from the 5mm adjacent to the surface and at a distance of 100mm from CCA treated wood sections, as described in 3.2.4. Soil sampled adjacent to 3 replicate sections was examined at each of the 6, 12, 18 and 24 month uplift periods for each of the four wood species.

The copper, chromium and arsenic content of each of these samples (96 in total, i.e. 3 replicates x 4 wood species x 4 sampling times x 2 sampling locations) was extracted and analysed according to the methods described in 2.2.4.2 and 2.2.4.3.

The data was tested statistically by analysis of variance to determine if significantly higher levels of copper, chromium or arsenic were present in soil adjacent to the pole sections compared with soil removed at a distance of 100mm from the sections. Species effects and the effect of increasing burial time were also statistically analysed by this method. In addition, the soil metal measurements were examined with dehydrogenase activity measurements (3.2.4) for significant correlations i.e. to determine if copper, chromium or arsenic in the soil affected the level of dehydrogenase activity.

3.3. RESULTS.

3.3.1. Soil Decay Potential.

Weight loss results for small, untreated lime woodblocks which were buried in each soil bed over the 24 months operation of the system are presented in Table 3.1. Average moisture contents of the blocks after burial are also given.

Table 3.1. Mean weight losses (%) and moisture contents (%) of untreated lime blocks after 6 week burial periods in soil beds.

No. of months after set up	Mean % weight loss*	Mean % moisture content*
1	41.2 ± 8.70	51.1 ± 9.10
5	52.9 ± 11.27	135.6 ± 22.36
16	42.6 ± 9.77	131.4 ± 17.94
23	39.2 ± 6.72	104.2 ± 19.71

* values represent the average of 72 woodblocks (4 blocks in 18 soil beds).

At each burial time, weight losses and moisture contents indicate that conditions within the soil beds were conducive to decay. Over the 24 month operational period, the lowest average percentage weight loss and moisture content for any one soil bed (4 replicates) was recorded as 26.3 ± 2.35% and 33.6 ± 4.75%,

respectively.

While a large increase in woodblock moisture content was recorded during the second burial period, it should be noted that the moisture content of soil in the beds only reached the desired level of 100% moisture content after 6 weeks of operation. This accounts for the low woodblock moisture content recorded at the first test period, and the significantly higher levels noted during subsequent burials

Results for individual tanks at later sampling periods, indicated that no single soil bed showed persistently high or low weight losses or moisture contents, suggesting that once the desired operating conditions had been reached (see section 3.2.1) the conditions within the system remained relatively constant.

3.3.2. Compatibility of Basidiomycete Mixed Inoculum.

Results from cross-reactivity testing of the brown and white rot fungi are shown in Figure 3.7(i) and (ii). Interactions between different organisms demonstrate a variety of effects. Most notably, the interaction of both *P. ostreatus* and *T. versicolor* against *N. lepideus*, resulted in overgrowth and killing of the brown rot organism (indicated by release of a red pigment into the agar and confirmed by lack of growth from cores subcultured from the interactive region). A similar reaction was caused by *T. versicolor* on *C. puteana* (Figure 3.7(ii)), however, the lethal effect and release of pigment was restricted to the initial point of contact between the two organisms. Although no obvious lysis was seen in the *C. puteana/P. ostreatus* cross

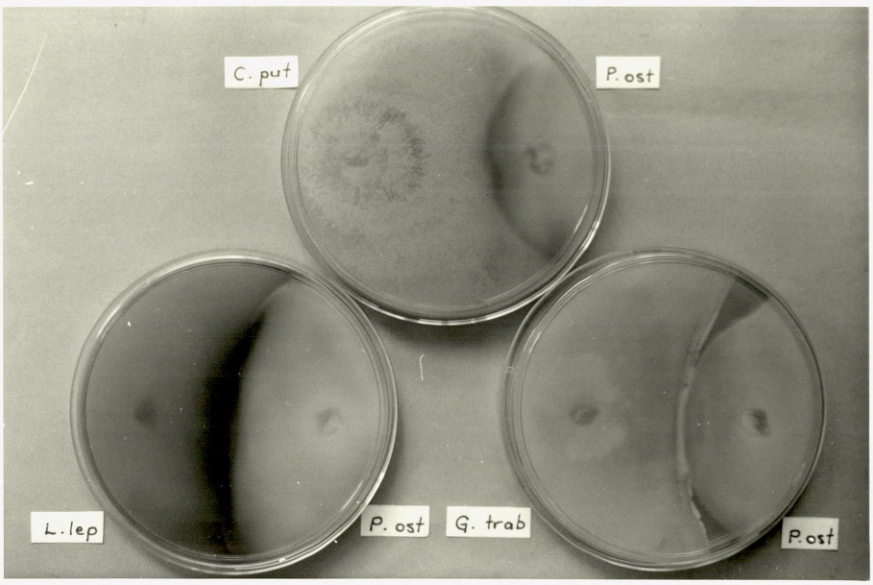


Figure 3.7(i). Cross-reactivity testing of the white rot organism *Pleurotus ostreatus* (P.ost) against the brown rot organisms *Coniophora puteana* (C.put), *Neolentinus lepideus* (L.lep) and *Gloeophyllum trabeum* (G.trab). Photos viewed from underside.

Figure 3.7(ii). Cross-reactivity testing of the white rot organism *Trametes versicolor* (C.vers) against the brown rot organisms *Coniophora puteana* (C.put), *Neolentinus lepideus* (L.lep) and *Gloeophyllum trabeum* (G.trab). Photos viewed from underside.

(Figure 3.7(i)), growth of *P. ostreatus* was inhibited, with accompanying overgrowth by *C. puteana*.

In the case of *G. trabeum*, a stalemate reaction occurred when tested against each of the two white rot organisms. In both instances, the two organisms grew together but no overgrowth or pigment release occurred. However, an unusual detrimental effect was caused by *P. ostreatus* where small globules of liquid were seen to exude from the *G. trabeum* mycelium at the point of contact.

The stalemate reaction between *G. trabeum* and *T.versicolor* appeared to produce no detrimental effect to either of the fungal species (Figure 3.7(ii)). This combination was therefore selected for use as the spray inoculum for application to the wood sections. Testing of the spray on malt extract agar plates confirmed viability of the two organisms in this form.

3.3.3. Dehydrogenase Assay of Soil.

Dehydrogenase activity of soil removed from soil beds are presented in Tables 3.2 and 3.3 for the basidiomycete and soft rot decay systems, respectively. Activity is expressed as umol of TTF formed per gram of soil per minute, and results are presented for samples removed from adjacent to the surface and at a distance of 100mm from control and CCA-treated wood sections at each sampling period.

The results indicate that at all sampling times, increased microbial activity was recorded at the surface of untreated control sections compared with background levels, i.e. at 100mm

Table 3.2. Dehydrogenase activity of soil samples removed from the surface and at a distance of 100mm from untreated control and CCA-treated wood sections buried within the basidiomycete decay system.

Burial period /months	Dehydrogenase Activity / umolTTFg^{-1} min^{-1} x10^{-5}			
	Untreated sections		CCA-treated sections	
	Surface	100mm	Surface	100mm
Corsican pine				
6	4.90	3.65	6.97±2.591	4.19±2.867
12	3.51±0.559	2.15±0.313	2.92±0.738	3.00±0.374
18	4.50±1.113	1.76±0.204	1.48±0.357	1.55±0.497
Scots pine				
6	7.64	3.06	6.50±2.474	4.93±2.021
12	5.47±0.840	2.50±1.230	2.66±0.490	2.79±0.899
18	3.38±1.483	1.94±0.208	1.34±0.426	1.33±0.576
Norway spruce				
6	7.82	2.13	5.76±2.314	4.28±1.973
12	4.86±0.937	2.41±0.276	2.92±0.369	3.62±0.838
18	4.43±1.466	1.42±0.396	1.15±0.258	1.71±0.321
Sitka spruce				
6	7.97	3.30	5.33±2.073	4.62±2.260
12	4.30±1.296	2.17±0.279	3.18±0.386	3.23±0.246
18	5.86±0.983	1.70±0.342	1.35±0.147	1.38±0.363

note: each value represents the mean of five replicate samples, except for the 6 month untreated controls, where only a single combined sample was analysed.

Table 3.3. Dehydrogenase activity of soil samples removed from the surface and at a distance of 100mm from untreated control and CCA-treated wood sections buried within the soft rot decay system.

Burial period /months	Dehydrogenase Activity / umolTTF$g^{-1}min^{-1}x10^{-5}$			
	Untreated sections		CCA-treated sections	
	Surface	100mm	Surface	100mm
Corsican pine				
12	4.71±1.732	3.23±0.552	3.33±0.476	3.35±0.130
18	3.45±0.624	2.01±0.234	1.17±0.454	1.34±0.335
24	2.12±0.696	1.24±0.225	1.28±0.398	1.47±0.259
Scots pine				
12	4.56±1.076	1.88±0.390	3.17±0.789	2.86±0.192
18	2.49±0.802	1.42±0.192	1.80±0.179	2.19±0.524
24	4.88±1.578	1.63±0.190	0.57±0.185	1.05±0.165
Norway spruce				
12	6.04±0.982	3.30±0.589	3.00±0.830	3.08±0.197
18	1.98±0.647	1.93±0.456	1.44±0.275	1.95±0.304
24	2.85±0.612	2.00±0.456	1.28±0.411	1.69±0.320
Sitka spruce				
12	5.54±1.429	2.15±0.127	2.79±0.539	3.39±0.372
18	5.54±1.407	2.30±0.306	1.10±0.239	1.05±0.597
24	3.88±0.980	1.79±0.333	1.19±0.401	1.35±0.336

note: each value represents the mean of five replicate samples.

from the sections. Though initially (after 6 months) increased activity was found at the surface of the CCA-treated sections, after 12 months and at subsequent sampling times, surface and background activity were similar, and in some cases background activity was slightly higher than the activity at the wood surface. Analysis of variance of the data showed the position of sampling to have a significant effect on the dehydrogenase activity in both test systems, with surface measurements significantly greater ($p < 0.0005$) than those at a distance of 100mm. This difference was found to be dependent on the presence or absence of CCA-treatment and confirmed that control sections caused an increase in soil activity at their surfaces. The presence of CCA-treatment however, resulted in no significant difference in surface and background activity measurements when results from all sampling times were combined.

Throughout the experiment, soil sampled adjacent to control sections showed higher microbial activity than soil adjacent to CCA-treated sections. This observation was confirmed statistically and showed activity measurements adjacent to control sections to be significantly higher ($p < 0.0005$) than those adjacent to CCA-treated wood sections. This suggests that the presence of CCA in the wood has a deleterious effect on microbial activity in the surrounding soil, and may therefore reduce the likelihood of decay. It should be noted, however, that the insertion of the treated material into the soil beds resulted in an initial increase (after 6 months) in microbial activity at the wood surface compared to background measurements.

Although there does not appear to be any major differences between the two test systems (Tables 3.2 and 3.3), the total activity measurements for each system were compared statistically and it was found that the basidiomycete test system showed significantly greater ($p < 0.0005$) activity than the soft rot system. This may be explained by the lack of a 6 month sampling period in the soft rot test system when an initial increase in activity was noted adjacent to both the untreated and CCA-treated pole sections. Species differences were also examined by analysis of variance and showed that there were no significant difference ($p > 0.05$) in the soil activity recorded adjacent to each of the four wood species.

It was apparent from Tables 3.2 and 3.3 that soil activity at the surface of control sections decreased with time. This effect was confirmed statistically using the data recorded for soil sampled at the surface of control sections after 12, 18 and 24 months soil burial, and showed a significant decrease ($p < 0.0005$) with increasing burial time. This decrease was found to occur irrespective of wood species. The overall microbial activity of the soil was also shown to deplete with time, by comparing background measurements recorded at 12 and 24 months after initiation of the experiment, i.e. 24 month measurements were significantly lower than 12 month measurements ($p < 0.05$).

3.3.4. Measurement of Surface Decay using Pilodyn.

The extent of surface decay of the curved and checked surfaces of each wood section was examined using the pilodyn instrument. Tables 3.4 and 3.5 present the pilodyn readings for the curved surfaces of sections removed from the basidiomycete and soft rot test systems respectively, whilst Tables 3.6 and 3.7 show the results for the checked surfaces of wood sections from the two test systems. Values for CCA-treated sections represent average measurements over the surface of five replicate wood sections, whilst control values represent the average measurement of a single section.

Comparison of pilodyn measurements recorded for sections exposed in the two test systems (Tables 3.4 and 3.5) shows there to be no major differences between the systems in either control or CCA-treated sections. In both test systems, pilodyn readings for untreated control sections were found to generally increase with increasing soil exposure. After 6 months burial, above ground measurements for control sections were considerably lower than those below ground, however, by 18 and 24 months burial there were no obvious differences between the two regions, indicating that decay had spread to above groundline locations. After 24 months burial, Sitka spruce was still showing increases in above and below ground readings indicating a progressive softening of the wood with time. In the other three species, however, similar readings at the 18 and 24 month sampling periods suggest that no further softening of the wood occurred after 18 months soil burial. This plateau in readings may however,

indicate that the maximum level of sensitivity of the pilodyn, as a measure of soft rot, had been reached.

Pilodyn measurements of the curved surfaces of CCA-treated sections (Tables 3.4 and 3.5) showed no increase over the 24 month burial period, suggesting that the presence of CCA had prevented the development of surface decay. In the case of the two pine species, the presence of the preservative caused a measurable hardening effect on the wood, as shown by reduced pilodyn penetration in unburied CCA-treated sections compared with unburied control sections. This effect is not apparent in the spruces, where control sections prior to burial show similar, or slightly lower pilodyn measurements than CCA-treated sections.

In all treated wood species, pilodyn readings from below groundline locations were slightly higher than those recorded for above groundline positions. This effect was entirely due to the slightly higher moisture levels of the wood in direct soil contact, and was not due to softening of the wood by decay organisms (see below in section 3.3.5).

Pilodyn measurements of the checked surfaces of CCA-treated and control sections (Tables 3.6 and 3.7) showed no consistent trend similar to that found in Tables 3.4 and 3.5. Individual readings were found to be variable, giving rise to large standard deviations and no evidence of a progressive softening of the timber with time.

Table 3.4. Pilodyn measurements for curved (tangential) surfaces of untreated control and CCA-treated wood sections buried within the basidiomycete decay system.

Burial time/months	Untreated sections		CCA-treated sections	
	Above GL	Below GL	Above GL	Below GL
Corsican pine				
0	9.1±0.56		7.4±1.20	
6	7.0±1.41	12.4±2.20	6.7±0.75	8.8±1.29
12	16.9±2.17	18.2±1.57	6.5±0.85	8.7±0.69
18	18.6±2.29	16.6±2.18	6.5±0.90	8.3±0.71
Scots pine				
0	10.8±0.20		7.4±1.15	
6	10.0±1.73	15.8±1.31	8.8±0.92	9.5±1.21
12	14.2±2.40	15.8±1.29	7.7±0.47	9.5±0.34
18	18.5±1.29	18.2±1.46	7.0±0.65	8.5±0.97
Norway spruce				
0	7.4±0.12		7.5±0.54	
6	9.0±0.82	13.9±2.12	8.1±1.43	8.9±0.83
12	10.4±2.29	15.7±1.91	8.5±0.98	9.3±0.32
18	17.5±1.22	20.1±2.58	7.3±0.64	8.4±0.56
Sitka spruce				
0	5.9±0.52		7.5±1.02	
6	7.9±2.06	13.6±1.51	7.4±1.02	7.9±0.81
12	14.0±5.41	17.8±1.56	7.3±0.74	8.1±1.21
18	*	*	7.4±1.03	8.4±1.05

* no pilodyn reading was obtained since the section was totally decayed.

Table 3.5. Pilodyn measurements for curved (tangential) surfaces of untreated control and CCA-treated wood sections buried within the soft rot decay system.

Burial time/months	Untreated sections		CCA-treated sections	
	Above GL	Below GL	Above GL	Below GL
Corsican pine				
0	9.1±0.56		7.4±1.20	
12	13.9±2.46	16.9±2.23	6.1±0.39	8.3±0.36
18	20.4±1.25	17.8±1.95	5.7±0.42	7.5±0.31
24	18.8±1.71	19.8±3.00	7.4±0.54	9.5±0.62
Scots pine				
0	10.8±0.20		7.4±1.15	
12	15.8±2.25	15.9±1.77	8.1±1.36	9.4±1.15
18	16.3±3.25	22.6±1.49	6.4±2.96	8.8±0.52
24	22.2±3.33	22.1±2.82	8.9±1.41	9.9±0.72
Norway spruce				
0	7.4±0.12		7.5±0.54	
12	16.1±1.55	16.6±1.93	8.7±0.37	9.2±0.23
18	19.8±2.02	21.0±2.63	7.6±0.64	9.1±0.37
24	17.0±3.16	19.1±3.72	8.4±0.58	9.6±0.77
Sitka spruce				
0	5.9±0.52		7.5±1.02	
12	6.8±0.96	10.0±2.02	7.6±0.82	8.6±0.84
18	13.9±3.84	17.3±1.57	7.3±0.96	8.4±0.68
24	18.5±2.16	21.9±1.92	8.1±1.19	8.9±1.20

Table 3.6. Pilodyn measurements for checked faces of untreated control and CCA-treated wood sections buried within the basidiomycete decay system.

T /m	Untreated sections		CCA-treated sections			
			CCA-treated region		Untreated region	
	Above GL	Below GL	Above GL	Below GL	Above GL	Below GL
Corsican pine						
0	11.1±0.27		8.9±1.30		NR	
6	11.0±2.16	13.5±1.56	8.8±2.33	10.6±1.46	NR	
12	13.9±2.02	16.0±1.28	8.8±1.00	10.8±0.59	NR	
18	16.8±3.23	15.2±2.33	8.4±0.86	10.2±0.70	NR	
Scots pine						
0	12.2±0.48		8.4±0.92		9.0±0.96	
6	10.4±1.80	12.3±1.75	9.5±1.95	9.9±0.90	9.4±2.80	10.3±0.58
12	14.6±2.32	15.3±2.33	8.4±0.62	9.2±0.86	10.1±1.85	11.9±1.84
18	12.4±4.38	15.2±2.91	8.2±1.13	9.5±1.50	8.8±1.81	10.6±1.43
Norway spruce						
0	10.2±1.08		8.4±0.59		10.6±1.46	
6	12.5±2.08	13.8±1.29	9.3±2.33	9.8±0.98	11.3±2.52	12.1±0.68
12	11.8±1.19	11.4±2.64	10.5±1.46	10.7±1.50	10.2±2.06	11.3±1.31
18	11.8±0.96	11.6±2.52	9.3±0.72	8.9±1.08	10.9±0.89	10.8±0.41
Sitka spruce						
0	9.1±0.32		NR		9.0±0.52	
6	6.2±1.04	9.3±2.32	NR		9.7±1.79	10.3±1.19
12	9.8±2.06	9.8±2.70	NR		9.0±1.33	11.2±1.55
18	*	*	NR		11.2±3.68	15.6±5.61

T/m - burial time/months.
* - no pilodyn reading recorded since section was totally decayed.
NR - not recorded (untreated/CCA-treated regions too narrow to obtain readings).

Table 3.7. Pilodyn measurements for checked faces of untreated control and CCA-treated wood sections buried within the soft rot decay system.

T /m	Untreated sections		CCA-treated sections			
	Above GL	Below GL	CCA-treated region		Untreated region	
			Above GL	Below GL	Above GL	Below GL
Corsican pine						
0	11.1±0.27		8.9±1.30		NR	
12	14.4±1.29	16.4±2.54	9.1±0.64	10.2±0.86	NR	
18	16.4±1.49	15.5±2.00	8.3±0.60	9.9±0.08	NR	
24	16.0±2.42	15.8±2.53	10.4±0.86	11.4±0.43	NR	
Scots pine						
0	12.2±0.48		8.4±0.92		9.0±0.96	
12	12.2±2.87	15.3±2.45	8.0±1.84	9.2±2.46	9.3±2.05	9.6±1.92
18	11.2±0.96	14.3±3.48	7.9±1.79	9.8±1.04	9.8±1.98	11.0±1.58
24	14.8±2.90	18.4±4.01	9.7±1.70	10.2±1.46	9.2±0.90	10.9±1.68
Norway spruce						
0	10.2±1.08		8.4±0.59		10.6±1.46	
12	11.4±1.70	13.1±1.87	9.7±0.97	9.9±1.72	9.6±2.44	11.7±2.15
18	13.0±1.41	15.3±5.14	10.9±2.37	10.9±1.82	10.4±1.09	11.3±1.89
24	13.8±1.66	14.8±3.11	9.9±1.25	11.5±0.66	11.1±1.80	12.6±0.40
Sitka spruce						
0	9.1±0.32		NR		9.0±0.52	
12	9.6±2.43	10.5±1.78	NR		9.7±1.71	11.0±1.23
18	8.8±0.64	9.3±2.69	NR		9.0±1.36	10.0±1.92
24	10.1±0.85	12.9±2.03	NR		10.6±0.47	11.0±0.66

T/m - burial time/months.
NR - not recorded (untreated/CCA-treated regions too narrow to obtain readings)

3.3.5. Measurement of Soft Rot by Microscopic Analysis.

Microscopic examination of small samples removed from the curved surfaces of CCA-treated wood sections confirmed that no soft rot decay cavities had developed in any of the four wood species, even after 24 months soil burial. In control sections however, soft rot was detected as early as the 6 months sampling period. Mean depths of soft rot penetration for the two sampling locations of control sections uplifted at each sampling time are presented in Table 3.8, whilst radial profiles of the severity of decay in these sections are presented in Figure 3.8. Microscopic examination of the wood fibres showed examples of each of the four categories (0, 1, 2 and 3) described in section 3.2.6. Photographs of fibres with soft rot severity of category 1, 2 and 3 are presented in Figures 3.9 (i) - (iii).

Control sections of all species suffered extensive soft rot of their curved surfaces which became more invasive with increasing burial time (Table 3.8). After 6 months burial, the four wood species showed similar patterns of soft rot penetration, as demonstrated in Figure 3.8. After 12 months, however, decay of Corsican pine controls had become noticeably more severe compared with the other wood species. At this point, it was obvious that the full depth of soft rot penetration had not been reached and it became apparent that soft rot extending from the curved surface had converged with that of the checked surface, resulting in the increasing decay index at 22-26mm from the curved surface (Figure 3.8). Due to the extensive nature of decay of this wood species, soft rot measurements were not

undertaken at subsequent sampling times. Comparison of the other three wood species shows similar patterns of radial invasion of soft rot, although slightly lower penetrations were recorded for Sitka spruce sections.

Table 3.8. Mean depths of soft rot penetration (mm) in control sections exposed to accelerated decay conditions.

Wood species	Sample Period /months			
	6	12	18	24
Basidiomycete system				
Corsican pine	14	>28*	*	
Scots pine	12	16	24	
Norway spruce	12	22	24	
Sitka spruce	10	16	**	
Soft Rot System				
Corsican pine		>28 *	*	*
Scots pine		16	26	24
Norway spruce		20	24	26
Sitka spruce		16	22	22

* - extensive soft rot present. Decay of curved and checked surfaces converged, thus a soft rot decay index of 0 never achieved.
** - section totally decayed by basidiomycete fungi.

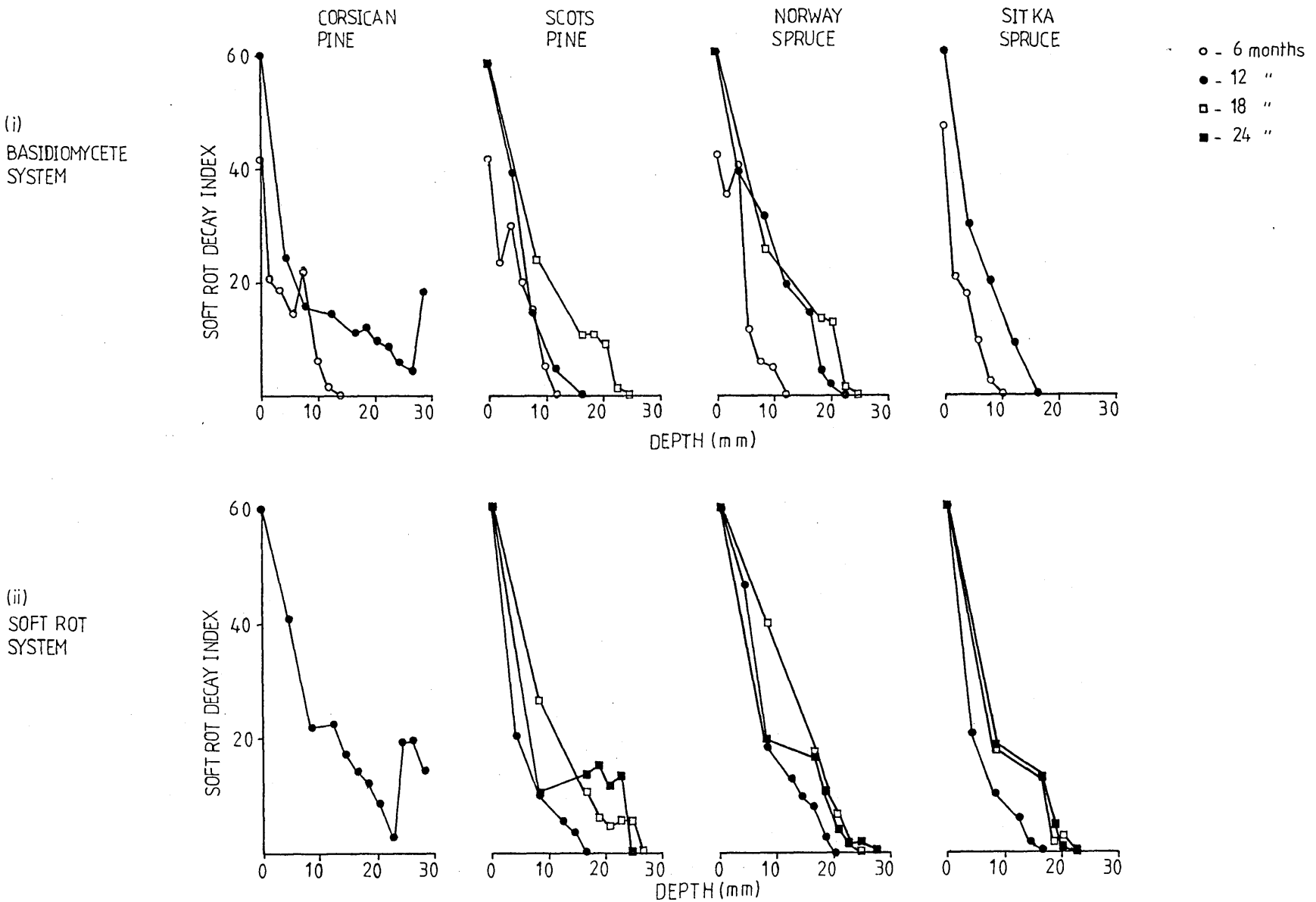


Figure 3.8. Soft rot decay indices for radial samples removed from untreated control sections after exposure to accelerated decay conditions.

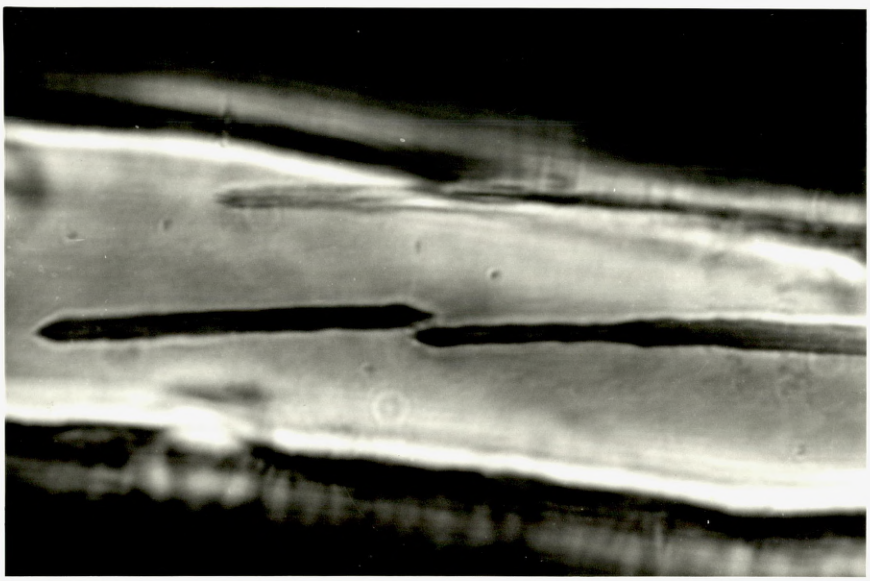


Figure 3.9(i). Wood fibre showing soft rot decay of category 1, i.e. less than 50% of cell wall covered with cavities. (x400 magnification)

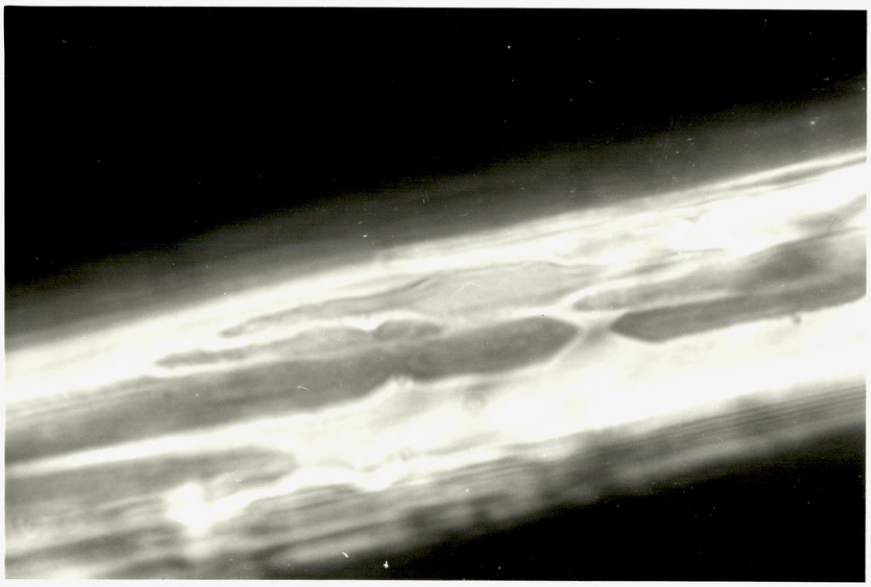


Figure 3.9(ii). Wood fibre showing soft rot decay of category 2, i.e. greater then 50%, but less than 100% of cell wall covered with cavities. (x400 magnification).

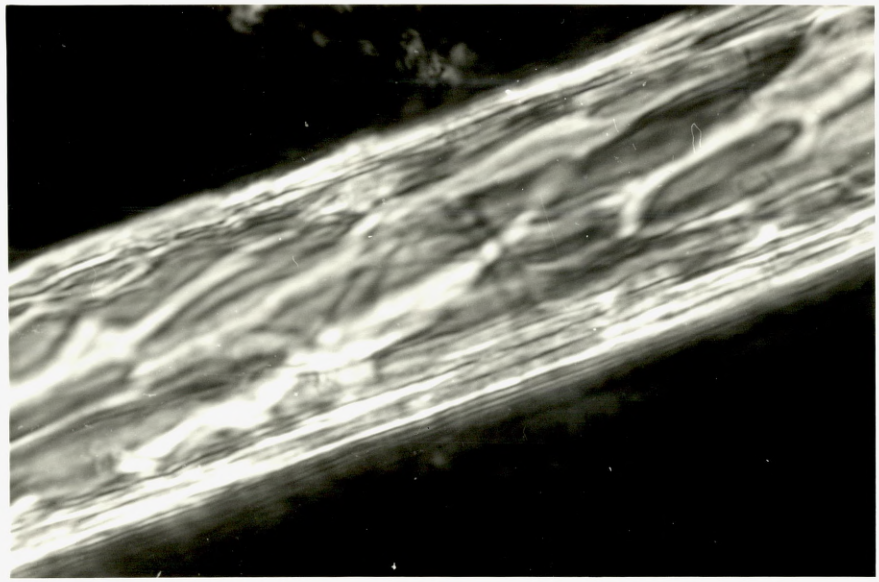


Figure 3.9(iii). Wood fibre showing soft rot decay of category 3, i.e. cell wall surface totally covered with large coalesced cavities or showing signs of splitting (x 400 magnification).

On visual examination of the checked surfaces of control sections at each sampling period, regions of grey/black discolouration with associated surface softening were observed. Figure 3.10 shows a photograph of this effect in each of the four wood species, and microscopic examination of small samples removed from these regions revealed the presence of soft rot cavities. Although depth of soft rot penetration was not measured on the checked surfaces of control sections it was obvious at each sampling time that Corsican pine was the most susceptible species to this type of decay. It was also noted that soft rot invasion had occurred irrespective of whether the wood had been sprayed with the basidiomycete inoculum.

Figure 3.10. Soft rot decay of checked surfaces of untreated control sections buried in the acclerated decay system for 18 months (these sections were typical of pole sections exposed in both the soft rot and basidiomycete test systems).

Whilst soft rot cavities were not found on the curved surfaces of CCA-treated wood sections, examination of their internal checked surfaces revealed the presence of soft rot, particularly in the untreated regions. All CCA-treated sections uplifted from the soft rot test system were therefore examined visually for signs of soft rot on their checked surfaces and small samples removed for microscopic examination. Table 3.9

records the number of sections of each species which were affected and gives the mean soft rot index of the sections at increasing depths from the checked surface.

Table 3.9. Soft rot decay indices for untreated regions of the checked surfaces of CCA-treated wood sections exposed in the soft rot test system.

Wood Species	Burial Time /months	Number of Affected Sections	Mean Soft Rot Decay Index at Increasing Depths /mm				
			0	2	4	6	8
Corsican pine	12	0	0				
" "	18	2	4	2	0		
" "	24	2	1	0			
Scots pine	12	0	0				
" "	18	2	4	0			
" "	24	2	7	0			
Norway spruce	12	1	7	7	0		
" "	18	3	14	3	0		
" "	24	2	26	2	0		
Sitka spruce	12	5	22	6	4	1	0
" "	18	5	23	4	2	0	
" "	24	2	22	10	6	2	0

It is apparent from Table 3.9. that the most severely affected species was Sitka spruce, which showed extensive soft rot cavitation on a large proportion of uplifted sections (i.e. 12 sections out of a total of 15 were affected). This result was probably due to the large area of untreated wood which is present in this species. In almost all the sections with existing soft rot, the decay occurred at the border between untreated and CCA-treated material. However, in one Sitka spruce section, soft rot cavitation was recorded within the CCA-treated region of the checked surface. As before, the area affected was near the border of untreated and CCA-treated material and would therefore contain very low levels of the preservative.

3.3.6. Measurement of Moisture Profiles.

Radial moisture profiles of CCA-treated and control sections uplifted from the two test systems at each sampling time, are presented in Figures 3.11 - 3.14 for Corsican pine, Scots pine, Norway spruce and Sitka spruce, respectively.

Radial moisture levels in the wood sections show wide variability which is dependent on both the wood species and the presence or absence of CCA treatment. Moisture profiles after 12 months burial indicate that untreated pine sections have very high surface moisture contents which are accompanied by high levels in the heartwood of the sections (Figures 3.11 and 3.12). Corsican pine, in particular, showed very high surface moisture levels up to 315%. In comparison with the pines, the untreated

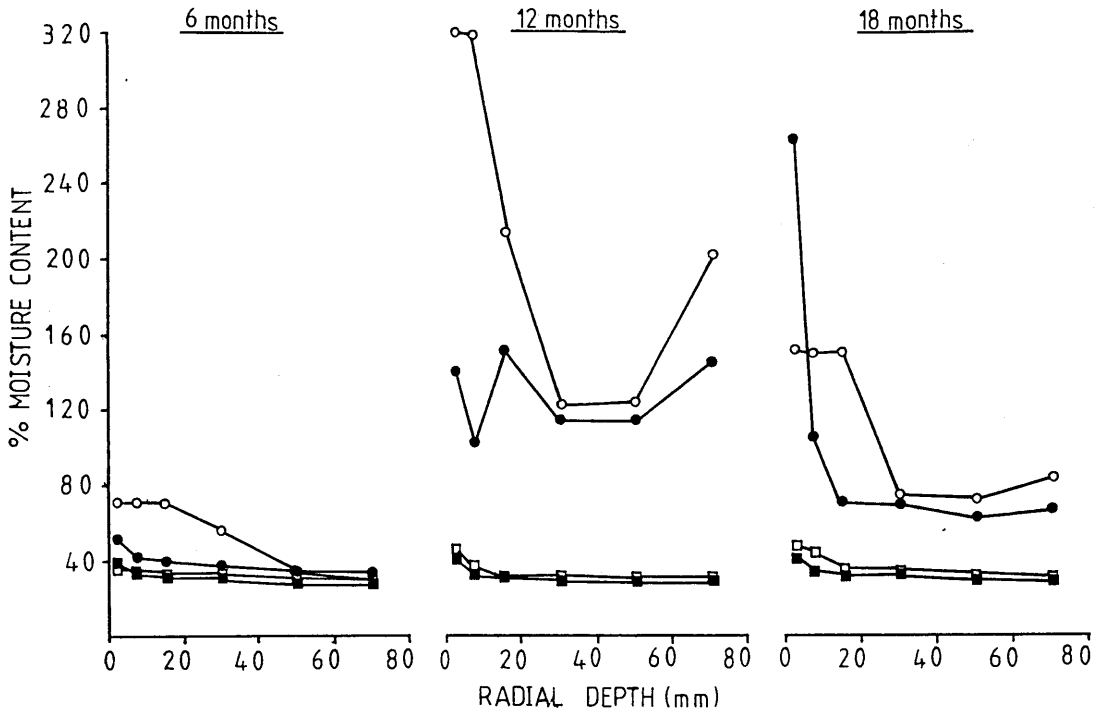
The legends below refer to Figures 3.11 - 3.14 on the following pages :-

Figure 3.11. Radial moisture profiles in untreated and CCA-treated Corsican pine pole sections exposed within, (i) the basidiomycete test system, and (ii) the soft rot test system.

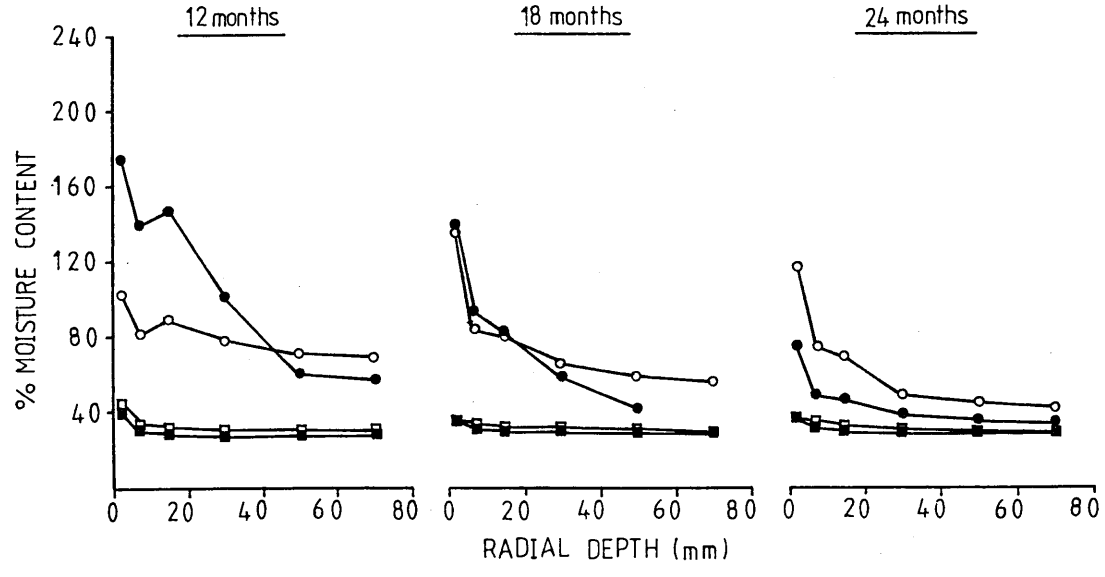
Figure 3.12. Radial moisture profiles in untreated and CCA-treated Scots pine pole sections exposed within, (i) the basidiomycete test system, and (ii) the soft rot test system.

Figure 3.13. Radial moisture profiles in untreated and CCA-treated Norway spruce pole sections exposed within, (i) the basidiomycete test system, and (ii) the soft rot test system.

Figure 3.14. Radial moisture profiles in untreated and CCA-treated Sitka spruce pole sections exposed within, (i) the basidiomycete test system, and (ii) the soft rot test system.



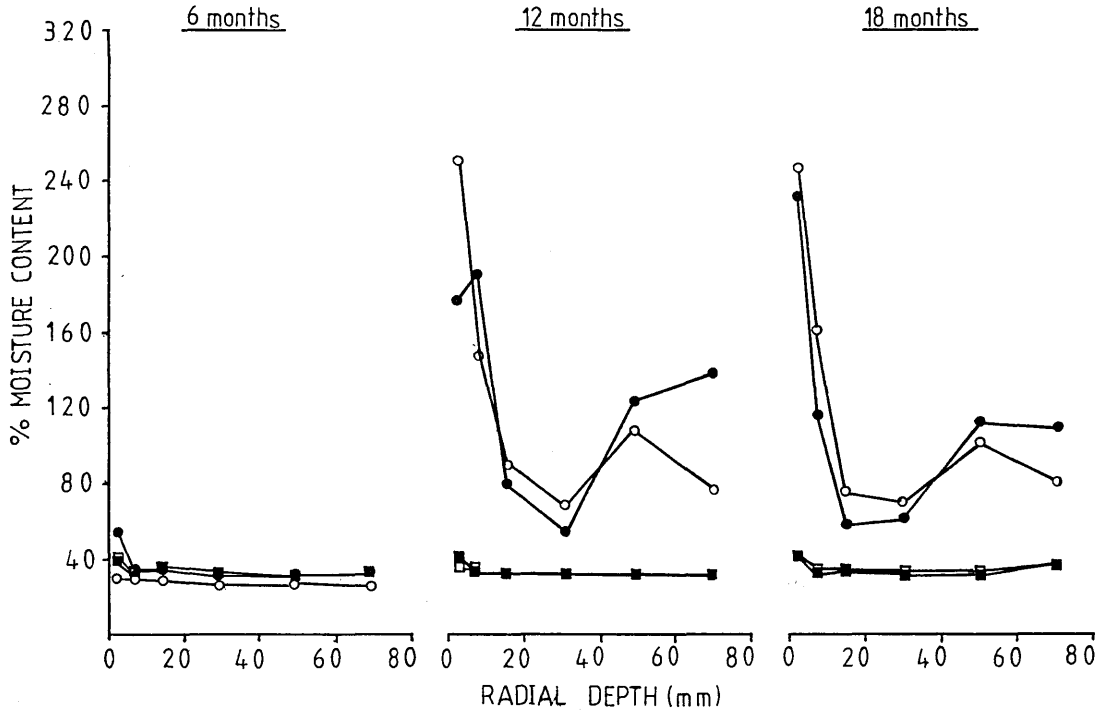
(i) BASIDIOMYCETE SYSTEM



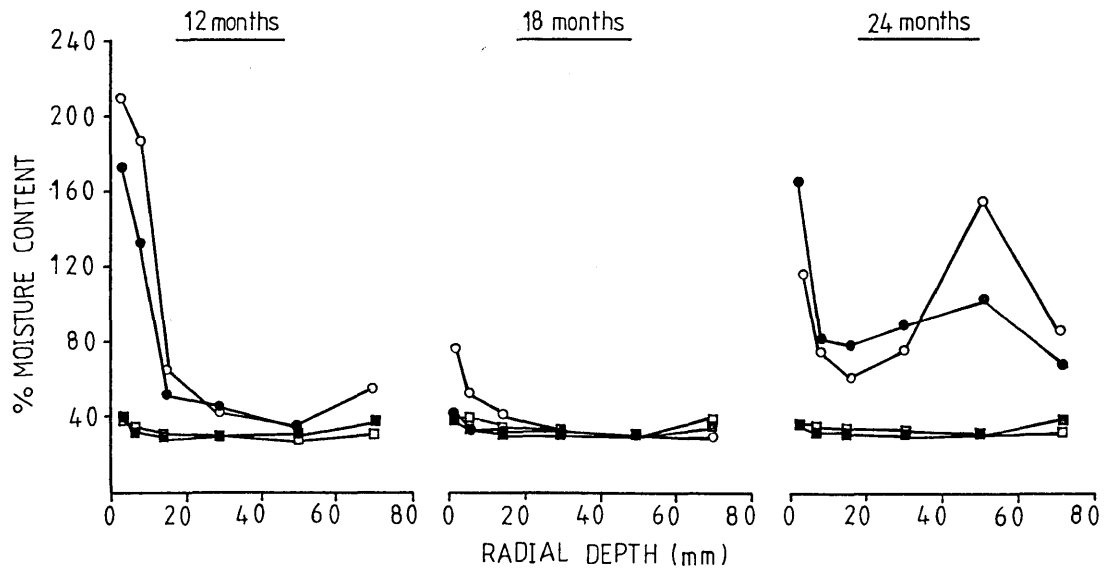
(ii) SOFT ROT SYSTEM

- ○ - control sections/checked surface
- ● - control sections/internal
- □ - CCA-treated sections/checked surface
- ■ - CCA-treated sections/internal

FIGURE 3.11: CORSICAN PINE



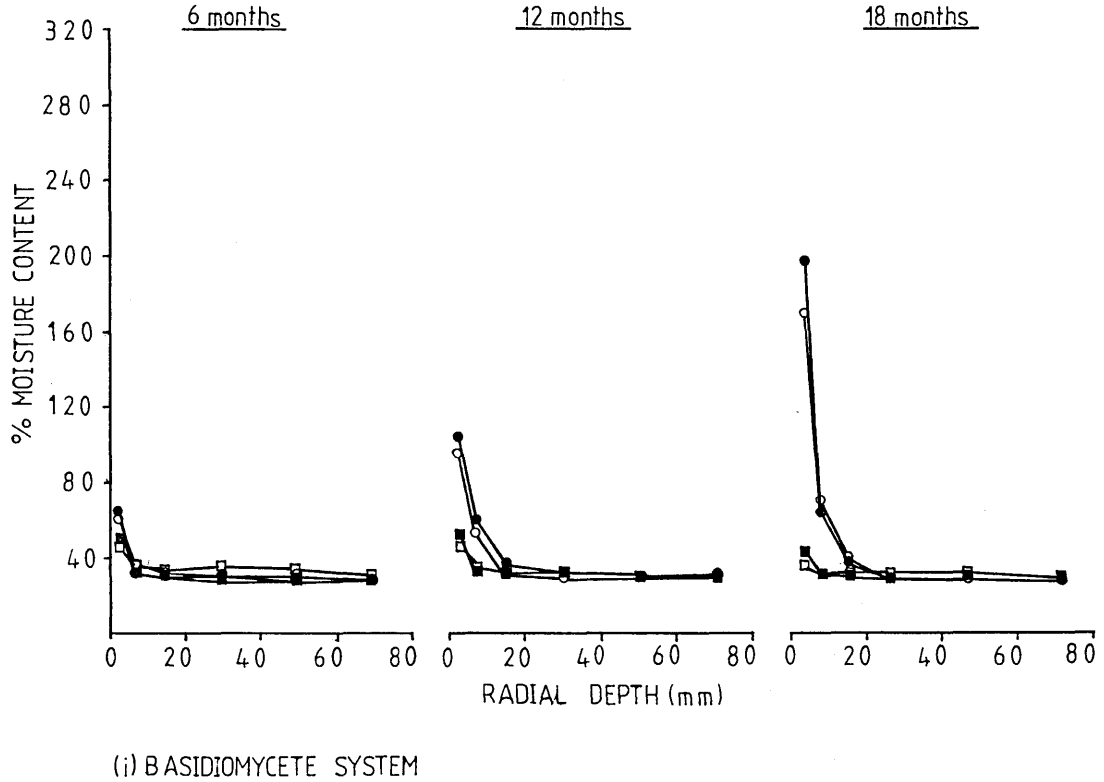
(i) BASIDIOMYCETE SYSTEM



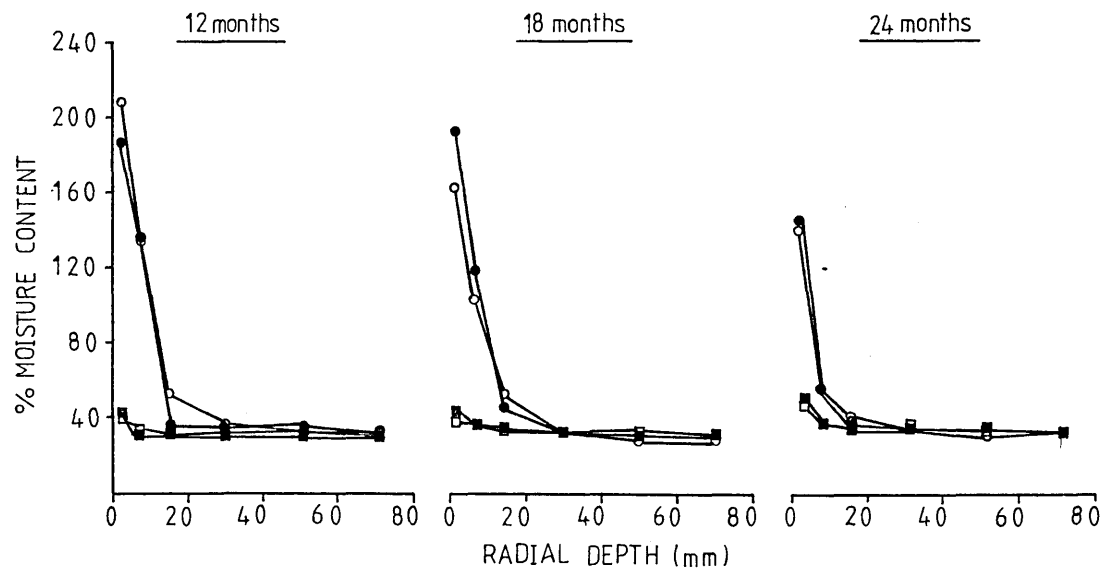
(ii) SOFT ROT SYSTEM

o-control sections/checked surface
•-control sections/internal
□-CCA-treated sections/checked surface
■-CCA-treated sections/internal

FIGURE 3.12: SCOTS PINE



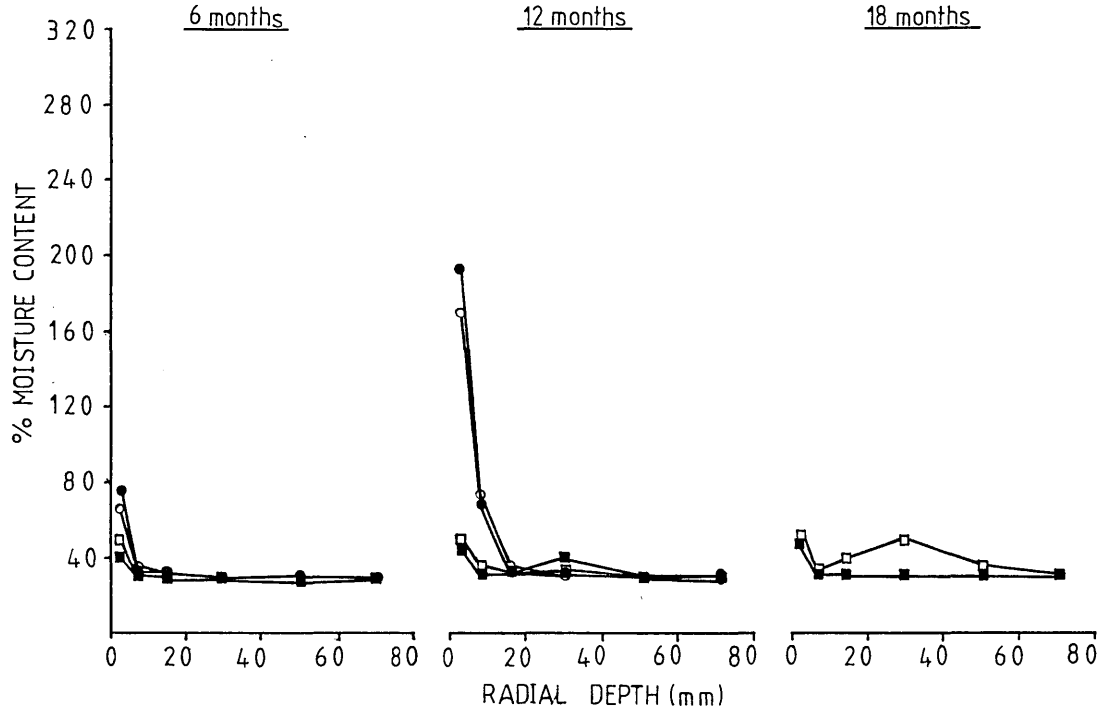
(i) BASIDIOMYCETE SYSTEM



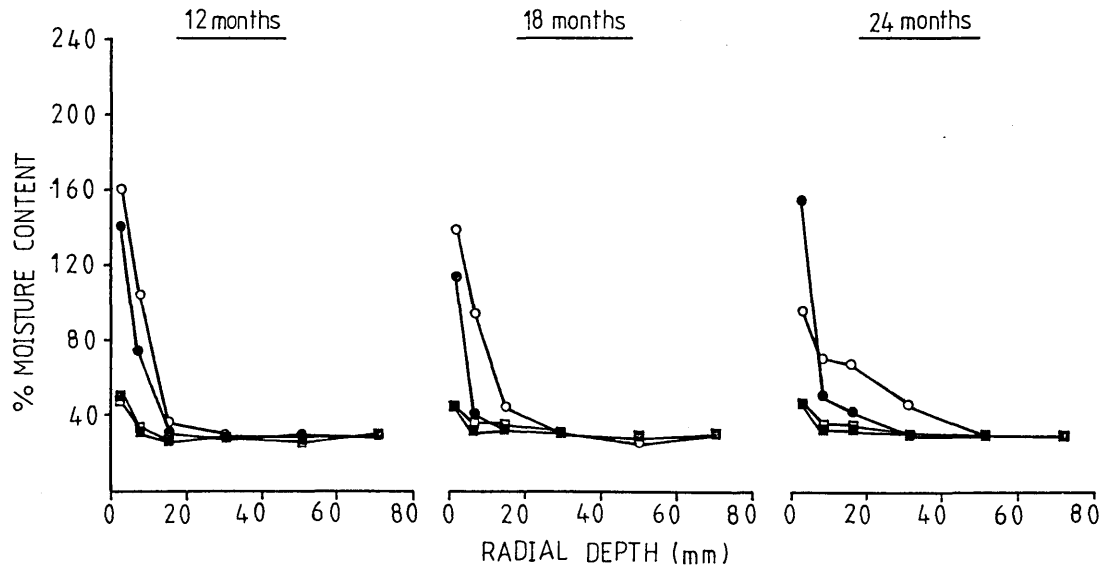
(ii) SOFT ROT SYSTEM

o-control sections/checked surface
•-control sections/internal
□-CCA-treated sections/checked surface
■-CCA-treated sections/internal

FIGURE 3.13: NORWAY SPRUCE



(i) BASIDIOMYCETE SYSTEM



(ii) SOFT ROT SYSTEM

o-control sections/checked surface
•-control sections/internal
□-CCA-treated sections/checked surface
■-CCA-treated sections/internal

FIGURE 3.14: SITKA SPRUCE

spruce sections showed much lower overall moisture contents at all sampling periods. While high surface measurements were recorded in these sections i.e. up to 200%, the radial profiles showed a sharp decline to ~30% at a position 20mm from the surface, which was maintained at or around this level through to the pith (Figures 3.13 and 3.14). High surface moisture levels recorded in each of the four untreated wood species were associated with the presence of soft rot decay, as shown by pilodyn and microscopic examination of these outer regions (sections 3.3.4 and 3.3.5, respectively).

High moisture contents recorded in untreated pines were not apparent when these species were CCA-treated by sap-displacement. In treated sections, moisture contents were maintained between 30 - 40% across the radial profile of all wood species. Treatment with CCA has therefore eliminated the species effect seen in the untreated sections. The presence of the preservative also conferred protection against decay, as reported in 3.3.4 and 3.3.5, thereby reducing further uptake of moisture as part of the decay process.

Moisture profiles were measured on samples removed from internal regions of the pole sections and along their checked surfaces to determine if soil packing in the checks and subsequent decay affected the wood moisture status. In general, there were few differences between measurements at these two locations, however, in the case of untreated Corsican pine after 12 months, and CCA-treated Sitka spruce after 18 months burial in the basidiomycete test system, moisture contents along the checked surfaces were shown to be consistently higher than

internal measurements (Figures 3.11(i) and 3.14(i)). These increased levels correlate well with the presence of decay along their checked surfaces caused by soft rot fungi in untreated Corsican pine (see section 3.3.5), and basidiomycete fungi in CCA-treated Sitka spruce sections (see section 3.3.7).

3.3.7. Decay of Checked Surface and Internal Cross-section.

Decay development was monitored by examination of both the checked and cross-sectional surfaces of each uplifted wood section, and an estimation of the percentage of surface area affected by decay was recorded as a visual decay index on a scale of 0-10. Results from this assessment are presented in Tables 3.10 and 3.11 for control and CCA-treated sections, respectively. Values in Table 3.10 represent the visual decay index for single sections uplifted at each sampling time, whilst values in Table 3.11 represent the mean measurement for the five replicate sections uplifted at each sampling time for each wood species. Untreated and CCA-treated regions of the treated sections were assessed separately but only results for the untreated areas are presented in Table 3.11.

Examination of the checked surfaces of untreated sections (Table 3.10) showed Corsican pine to be more heavily decayed than the other three control species. As early as 6 months after soil burial, decay covered 90% of the checked surface area of untreated Corsican pine and after 18 months burial total cover by decay was observed. Comparison of the remaining three species shows Scots pine and Norway spruce suffering a similar extent of

Table 3.10. Visual decay indices for checked and cross-sectional surfaces of control sections exposed to accelerated decay conditions.

Wood Species	Visual Decay Index							
	Checked surface				Cross-section			
	6	12	18	24/m	6	12	18	24/m
Basidio. System								
Corsican pine	9	9	10	NT	1	2	2	NT
Scots pine	2.5	7	6.5	NT	1	3	2	NT
Norway spruce	3	3	6.5	NT	1	2	2	NT
Sitka spruce	1	3	10	NT	1	1.5	10	NT
Soft Rot System								
Corsican pine	NT	9	10	10	NT	2	2.5	1
Scots pine	NT	6.5	5	8	NT	2	3	2
Norway spruce	NT	3	6	7	NT	2	2	2
Sitka spruce	NT	3	2	4	NT	1	2	2

Table 3.11. Visual decay indices for untreated regions of checked and cross-sectional surfaces of CCA-treated sections exposed to accelerated decay conditions.

Wood Species	Visual Decay Index							
	Checked surface				Cross-section			
	6	12	18	24/m	6	12	18	24/m
Basidio. System								
Corsican pine	0	0	0	NT	0	0	0	NT
Scots pine	0.3	0.4	1.1	NT	0	0	0.2	NT
Norway spruce	1.1	3.2	2.1	NT	0.5	0.7	0.2	NT
Sitka spruce	1.0	2.7	6.0	NT	0.2	1.3	3.6	NT
Soft Rot System								
Corsican pine	NT	0	0.4	0.4	NT	0	0	0
Scots pine	NT	0	0.4	0.4	NT	0	0	0
Norway spruce	NT	1.0	0.6	0.7	NT	0	0	0
Sitka spruce	NT	1.0	1.2	0.8	NT	0	0	0

m - months of soil burial.
NT - not tested i.e. no sections uplifted at this time.

decay, although the rate of decay development was slightly faster in the Scots pine controls. Sitka spruce generally showed very slow progression of surface decay with only 40% of the checked surfaces decayed after 24 months soil exposure in the soft rot test system. These differences in decay severity of the checked surfaces of the four control species are clearly illustrated in Figure 3.10.

Examination of the cross-sections of control samples showed little difference between the four wood species (Table 3.10). In all cases, the soft rot decay extended inwards from the curved surfaces and increased slightly with increasing soil burial time.

One obvious anomaly to the above results was the Sitka spruce section exposed in the basidiomycete test system for 18 months. Fungal mycelium was observed protruding from the top of this section after only 6 months soil burial, and after 18 months soil burial it was found to be totally decayed by basidiomycete fungi, resulting in a visual decay index of 10 for both its checked and internal regions. Of all the untreated control sections artificially inoculated with basidiomycete fungi, this was the only section to show colonisation and decay by this type of decay organism. A photograph of this section is given in Figure 3.15 and clearly shows the extensive decay caused by basidiomycete decay fungi (brown rot decay).

Figure 3.15. Brown rot decay of an untreated Sitka spruce pole section after burial in the basidiomycete test system for 18 months (note the fungal mycelium on checked surfaces).

Except for the anomaly mentioned above, decay of all control sections, irrespective of whether they were artificially inoculated with decay fungi, was caused entirely by soft rot

organisms. The decay appeared grey/black in colour and often showed a speckled effect, which can clearly be seen in the Corsican pine section in Figure 3.16.

Figure 3.16. Soft rot decay of checked surfaces of an untreated Corsican pine section (note the grey/speckled appearance typical of this type of decay)

In contrast to the above results, totally different patterns of decay were observed in CCA-treated pole sections (Table 3.11). Unlike untreated control sections which showed similar decay patterns in both the basidiomycete and soft rot test systems, in CCA-treated sections, large differences existed between results from the two systems. In the soft rot test system, sections generally showed very little soft rot decay of the checked surfaces compared with untreated controls. It was noticable however, that the two spruce species showed greater levels of soft rot than the two pine species. As shown in Table 3.11, the exposure of CCA-treated sections in the soft rot decay system resulted in no decay of internal regions (cross-sectional surfaces) of any of the four wood species. Decay was restricted entirely to the checked surfaces and consistently occurred at the border of untreated and CCA-treated material. Examination of the CCA-treated regions of the sections, as shown in Table 3.12, showed slight decay development in the two spruce species. As stated earlier, the area affected was at the border of untreated/treated material, therefore would contain very low levels of the CCA preservative.

Table 3.12. Visual decay indices for CCA-treated regions of the checked surfaces of pole sections buried in the basidiomycete and soft rot test systems.

Species	Basidiomycete System			Soft Rot System			
	6	12	18	12	18	24	/months burial
Corsican pine	0	0	0	0	0	0	
Scots pine	0	0	0	0	0	0	
Norway spruce	0	0	0	0.5	0	0	
Sitka spruce	0	2	2	2.5	1	2.5	

Decay of CCA-treated sections was found to be greatly increased after spraying with the basidiomycete inoculum. As in the soft rot system, the spruces were more severely affected than the pines and Corsican pine was found to be totally protected against any form of decay (Table 3.11). In the case of Scots pine, slight decay, which appeared to be brown rot, occurred on the checked surfaces of sections uplifted at each sampling time. As before, decay occurred at the border region between untreated and CCA-treated material. Decay of the spruce pole sections was more severe, particularly in Sitka spruce which showed a mean visual decay index of 6.0 (i.e. an average of 60% of the untreated region was covered by decay) after 18 months soil burial. Decay was predominantly brown rot, located at the border region of the CCA-treatment in those sections uplifted after 6 months burial. In sections uplifted after 18 months however, the decay appeared to have spread from this location towards the pith, thereby affecting almost all untreated material (Figure

3.20). Photographic profiles of all sections removed from the basidiomycete test system after 18 months burial are presented in Figures 3.17 - 3.20, and show the increasing severity of brown rot decay from Corsican pine (Figure 3.17) to Sitka spruce (Figure 3.20).

It is obvious from Table 3.11, that CCA-treated sections inoculated with basidiomycete organisms showed extensive decay of internal regions (cross-sectional surfaces), particularly Sitka spruce (see Figures 3.21 and 3.22). In most of the CCA-treated pine sections, decay was either minimal (Scots pine) or totally absent (Corsican pine), however, pockets of brown rot decay were regularly observed in the spruce sections. In Norway spruce, decay appeared as very small brown/orange pockets occurring immediately behind the CCA-treated region, as shown in Figure 3.23. Decay of Sitka spruce was much more extensive with 3 out of 5 sections showing heavy brown rot decay after 12 and 18 months soil burial, as shown in Figures 3.21 and 3.22, respectively. In most cases, the decay occurred along the sprayed checks, however, in some sections internal pockets of decay occurred which were spatially separate from the originally inoculated check (Figure 3.21(b) and (c), Figure 3.22(a)).

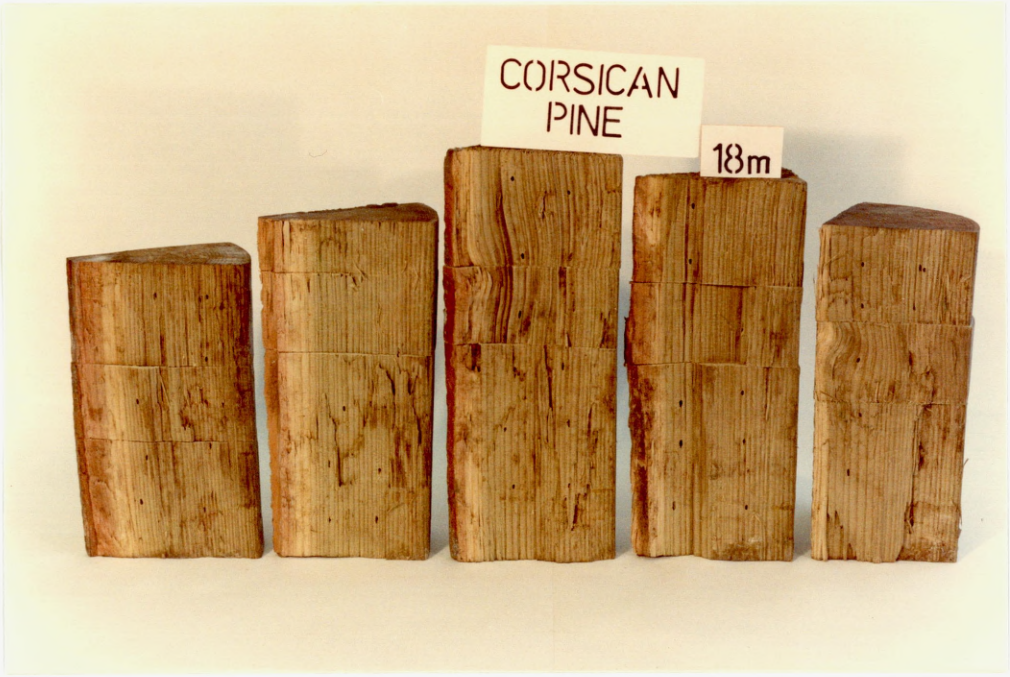


Figure 3.17. Checked surfaces of CCA-treated Corsican pine pole sections showing deep preservative penetration and lack of decay development after 18 months burial in the basidiomycete decay system.

Figure 3.18. Checked surfaces of CCA-treated Scots pine pole sections showing slight decay development of the untreated region after 18 months burial in the basidiomycete test system.

Figure 3.19. Checked surfaces of CCA-treated Norway spruce pole sections showing brown rot decay of the untreated region after 18 months burial in the basidiomycete decay system.

Figure 3.20. Checked surfaces of CCA-treated Sitka spruce pole sections showing extensive brown rot decay of the untreated region after 18 months burial in the basidiomycete test system.

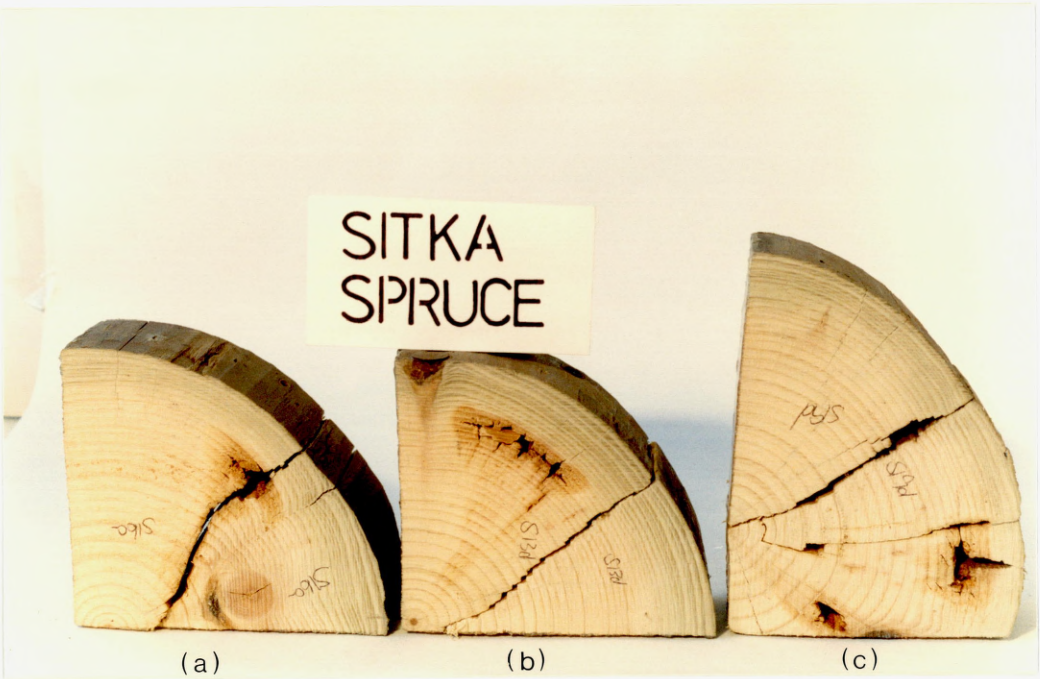


Figure 3.21. Cross-sectional surfaces of CCA-treated Sitka spruce pole sections showing brown rot decay, (a) along the check, and (b) at internal positions, after only 12 months burial in the basidiomycete test system.

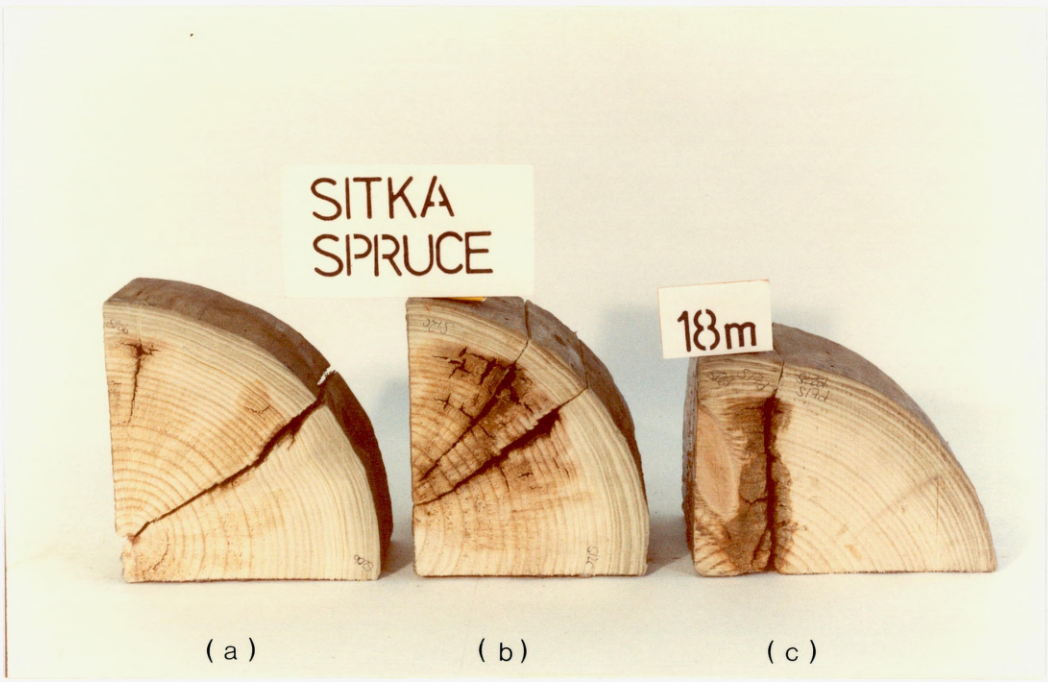


Figure 3.22. Cross-sectional surfaces of CCA-treated Sitka spruce pole sections showing extensive brown rot decay at the checked surface (b and c), and at internal positions (a), after 18 months burial in the basidiomycete test system.

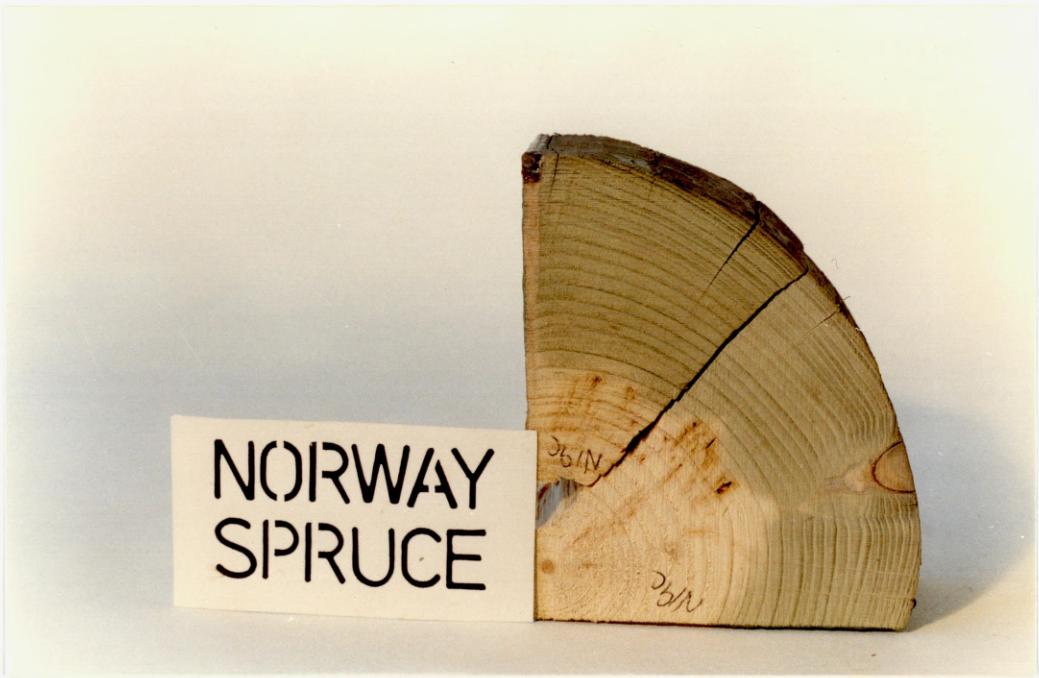


Figure 3.23. Cross-section of CCA-treated Norway spruce pole section after burial in the basidiomycete test system for 12 months, and showing the presence of small pockets of internal brown rot decay.

In summary, results for visual examination of the decay of untreated control and CCA-treated sections showed that:-

(i) decay of control sections was caused predominantly by soft rot organisms, irrespective of artificial inoculation by basidiomycete decay fungi. Decay of these sections was limited to their curved and checked surfaces.

(ii) the extent of decay of control sections could be ranked as Corsican pine > Scots pine > Norway spruce > Sitka spruce.

(iii) decay of CCA-treated sections was found to be greatly affected by artificial inoculation with basidiomycete fungi.

Treated sections exposed in the soft rot test system showed very low levels of soft rot decay, whereas those exposed in the basidiomycete test system suffered extensive brown rot decay, particularly Sitka spruce.

(iv) decay of CCA-treated sections was predominantly brown rot, and the extent of decay could be ranked as Sitka spruce >> Norway spruce > Scots pine > Corsican pine.

3.3.8. Isolation of Fungal Colonisers.

Mould Organisms.

A wide variety of deuteromycetes were isolated from both control and CCA-treated pole sections, although in most instances these mould colonisers were not associated with obvious pockets of decay. These organisms included the following :-

Trichoderma spp.

Graphium spp.

Penicillium spp.

Aspergillus spp.

Trichurus spp.

Fusarium spp.

Gliocladium spp.

Sporotrichum spp

Byssochlamys nivea Westling. (identified at CAB International, Mycological Institute, Surrey).

Each of the above species were isolated from both untreated and CCA-treated regions of each of the four wood species. The most common isolates were *Trichoderma* spp. and *Graphium* spp. (commonly isolated at every sampling time), however, at the 12 and 18 month sampling times, *Penicillium* spp. were also widely isolated. At the 18 month uplift, a previously unisolated organism was recorded, namely *Sporotrichum* spp., which was also isolated at the final uplift.

Comparison of isolations from the basidiomycete and soft rot test systems, showed there to be no obvious differences i.e. most isolates were common to both test systems.

Basidiomycete Organisms.

Although isolations were attempted from all sections uplifted from both soft rot and basidiomycete test systems, basidiomycetes were only isolated from CCA-treated sections of Sitka and Norway spruce which had been artificially inoculated with the basidiomycete fungi. A summary of numbers of basidiomycete isolates and their location within the wood sections are reported in Table 3.13.

Table 3.13. Occurrence and location of basidiomycetes in CCA-treated Sitka and Norway spruce sections after soil burial.

Sampling Time(months)	Number of Sections from which Isolates were Recovered	Location of Positive Isolations
6	1 Sitka spruce	checked region
	1 Norway spruce	checked region
12	5 Sitka spruce	checked & internal regions
	2 Norway spruce	checked & internal regions
18	5 Sitka spruce	checked & internal regions
	3 Norway spruce	checked & internal regions

In all cases, the fungal isolates appeared culturally and morphologically identical to each other and to *G. trabeum* (Pers:Fr)Murr, the brown rot organism in the artificial inoculum. Basidiomycetes were found in both the checked region (i.e. at the site of initial inoculation), and from internal regions of the sections (Table 3.13). In some instances, these internal pockets of decay were entirely separate from the inoculated check and appeared to be separated by sound timber (Figure 3.21(b) and (c), Figure 3.22 (a)).

3.3.9. SDS-PAGE Analysis of Basidiomycete Isolates.

Basidiomycete isolates from Sitka and Norway spruce sections were analysed by SDS-PAGE to compare their molecular profiles against those of *G. trabeum* and *T. versicolor*. The isolates examined originated from untreated regions of CCA-treated Sitka and Norway spruce sections uplifted from the basidiomycete test system after 6, 12 and 18 months soil burial (see Table 3.13). Cultures included isolates from both the checked and internal regions of the sections. Photographs of the gels for Sitka and Norway spruce are presented in Figures 3.24 and 3.25, respectively.

Visual examination of the gels indicated that all isolates from the Sitka spruce wood sections (Figure 3.24) were similar to one another, as were isolates from Norway spruce sections (Figure 3.25). It was also apparent from the gels that all isolates from the wood sections showed very close similarity to *G. trabeum* (Pers:Fr)Murr. These visual observations were verified by calculating a similarity matrix for each isolate compared with *G. trabeum* (Pers:Fr)Murr and *T. versicolor* (L. ex Fr.)Pilate.

Molecular profiles of each mycelial extract were determined by calculating the Rf values of each of its protein bands (i.e. measurement of the distance travelled by each protein band relative to the solvent front). A similarity matrix between any two isolates was then calculated as follows:-

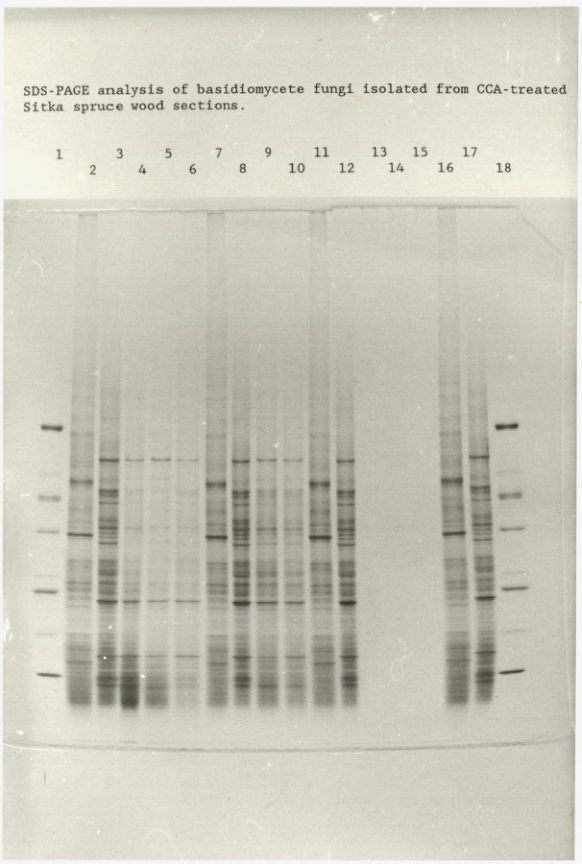


Figure 3.24. SDS-PAGE analysis of basidiomycete fungi isolated from CCA-treated Sitka spruce wood sections.

Lane No.	Sample
1 & 18	molecular weight standards
2,7,11 & 16	*T. versicolor*(FPRL 28B) - reference species
3,8,12 & 17	*G. trabeum* (BAM Ebw. 109) - reference species
4	isolate from checked surface after 6 months burial
5	isolate from checked surface after 12 months burial
6	isolate from internal site after 12 months burial
9	isolate from checked surface after 18 months burial
10	isolate from internal site after 18 months burial
13,14 & 15	wood samples from decayed region (analysis proved unsuccessful)

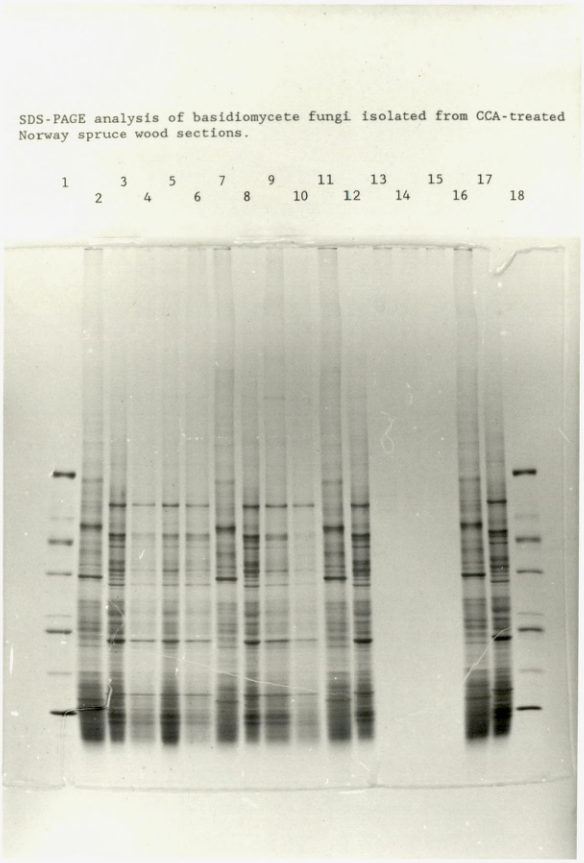


Figure 3.25. SDS-PAGE analysis of basidiomycete fungi isolated from CCA-treated Norway spruce wood sections.

Lane No.	Sample
1 & 18	molecular weight standards
2,7,11 & 16	*T. versicolor*(FPRL 28B) - reference species
3,8,12 & 17	*G. trabeum* (BAM Ebw. 109) - reference species
4	isolate from checked surface after 6 months burial
5	isolate from checked surface after 12 months burial
6	isolate from internal site after 12 months burial
9	isolate from checked surface after 18 months burial
10	isolate from internal site after 18 months burial
13,14 & 15	wood samples from decayed region (analysis proved unsuccessful)

e.g. Comparison of isolates A and B.

Similarity Matrix =

$$\frac{\text{No. of Bands in A and B with Identical Rf Value}}{\text{Total No. Bands in A}} \times 100\%$$

Comparison of all isolates from Sitka spruce sections showed a similarity matrix of 100% (23 bands common to all five isolates), confirming that they were indeed all identical. Similarly, isolates from Norway spruce sections were also found to be identical i.e. 25 bands were identified, all of which were common to each of the five isolates. The molecular profiles of isolates from the sections were then compared to those of *G. trabeum* and *T. versicolor* and similarity matrices were determined. The results are presented in Table 3.14.

Table 3.14. Similarity matrices for basidiomycetes isolated from wood sections compared with *G. trabeum* and *T. versicolor*.

Reference Species	Sitka Spruce Isolates			Norway Spruce Isolates		
	No. of Bands	No. of Common Bands	Similarity Matrix	No. of Bands	No. of Common Bands	Similarity Matrix
G.trabeum	28	23	82.1	31	25	80.6
T.versi-color	27	3	11.1	32	5	15.6

The results presented in Table 3.14 confirm that all fungal cultures isolated from the wood sections were indeed *G. trabeum*. In each case, all protein bands present in the molecular profiles of wood isolates were also present in the profile for *G. trabeum*. The additional bands observed for *G. trabeum* were probably due to the clearer and more pronounced profiles obtained for this extract, and it was expected that a slightly higher concentration of mycelial extract for the wood isolates may have resulted in the appearance of these additional bands.

Comparison of the wood isolates with *T. versicolor* showed very low similarity matrices, indicating that *T. versicolor* was not re-isolated from any of the exposed pole sections.

3.3.10. Cross-Reactivity Studies of Basidiomycetes with Mould Isolates.

The nine mould fungi isolated from the buried wood sections (see section 3.3.8) were tested against *G. trabeum* and *T. versicolor* to determine if any were antagonistic to either of the basidiomycetes used to inoculate the sections. Each interaction was recorded as either;

(i) stalemate - no apparent antagonistic effects on either organism

(ii) overgrowth - where one protagonist was overgrown by its competitor without any obvious signs of fungal lysis or killing

or,

(iii) killing - indicated by lysis and accompanied by the release of red pigment into the agar. Confirmed by lack of growth from cores subcultured from the interactive region

Results for each interaction are summarised in Table 3.15.

Table 3.15. Interactive results from cross-reactivity studies of mould isolates against *G. trabeum* and *T.versicolor*.

Mould Isolate	Basidiomycete	Interactive Result
Trichoderma	*G.trabeum*	Killing of *G. trabeum*
	T.versicolor	Killing of *T. versicolor*
Graphium	*G.trabeum*	Overgrowth of *Graphium*
	T.versicolor	Overgrowth of *Graphium*
Penicillium	*G.trabeum*	Slight overgrowth of *G. trabeum*
	T.versicolor	Slight overgrowth of *T. versicolor*
Aspergillus	*G.trabeum*	Stalemate
	T.versicolor	Stalemate
Trichurus	*G.trabeum*	Slight overgrowth of *Trichurus*
	T.versicolor	Overgrowth of *Trichurus*
Fusarium	*G.trabeum*	Killing of *G. trabeum*
	T.versicolor	Killing of *T. versicolor*
Gliocladium	*G.trabeum*	Killing of *G. trabeum*
	T.versicolor	Killing of *T. versicolor*
Sporotrichum	*G.trabeum*	Slight overgrowth of *Sporotrichum*
	T.versicolor	Overgrowth of *Sporotrichum*
B. nivea	*G.trabeum*	Killing of *B. nivea*
	T.versicolor	Killing of *B. nivea*

From Table 3.15 it can be concluded that each mould isolate had a similar effect on the growth of both *G. trabeum* and *T. versicolor*. It is apparent that *Trichoderma*, *Fusarium* and

Gliocladium, are capable of killing the basidiomycetes under the test conditions but the effect does not appear to be selective against either of the two decay fungi.

3.3.11. CCA-Analysis of Wood Sections.

3.3.11.1. Effect of Wetting Wood Sections Prior to Soil Burial.

Radial profiles of copper, chromium and arsenic concentration in wood sections before and after wetting to 30% moisture content are presented in Figures 3.26 - 3.29. Each value on the graphs represents the average of four replicates and are recorded on a % weight/weight basis (metal/wood). Profiles are recorded for radial samples removed from both the checked surfaces and internal regions of treated sections of each of the four wood species.

It is apparent from Figures 3.26 - 3.29 that radial profiles for the three metals generally show the same patterns observed in the field poles (see section 2.3.1). It is also apparent that the levels of copper, chromium and arsenic are similar in pre- and post-wetting samples, therefore showing no losses of the preservative components during the wetting process. Wetting of the wood sections did however, result in slight redistribution of the preservative components towards pole centres.

In addition to measuring the copper, chromium and arsenic contents of the wood, their concentration in the water used to soak the wood sections was also determined. Metal concentrations in the water were related to the original dry weight of the

The legends below refer to Figures 3.26 - 3.29 on the following pages :-

Figure 3.26. Copper, chromium and arsenic retentions in radial samples removed from CCA-treated Corsican pine pole sections before and after wetting to 30% moisture content.

Figure 3.27. Copper, chromium and arsenic retentions in radial samples removed from CCA-treated Scots pine pole sections before and after wetting to 30% moisture content.

Figure 3.28. Copper, chromium and arsenic retentions in radial samples removed from CCA-treated Norway spruce pole sections before and after wetting to 30% moisture content.

Figure 3.29. Copper, chromium and arsenic retentions in radial samples removed from CCA-treated Sitka spruce pole sections before and after wetting to 30% moisture content.

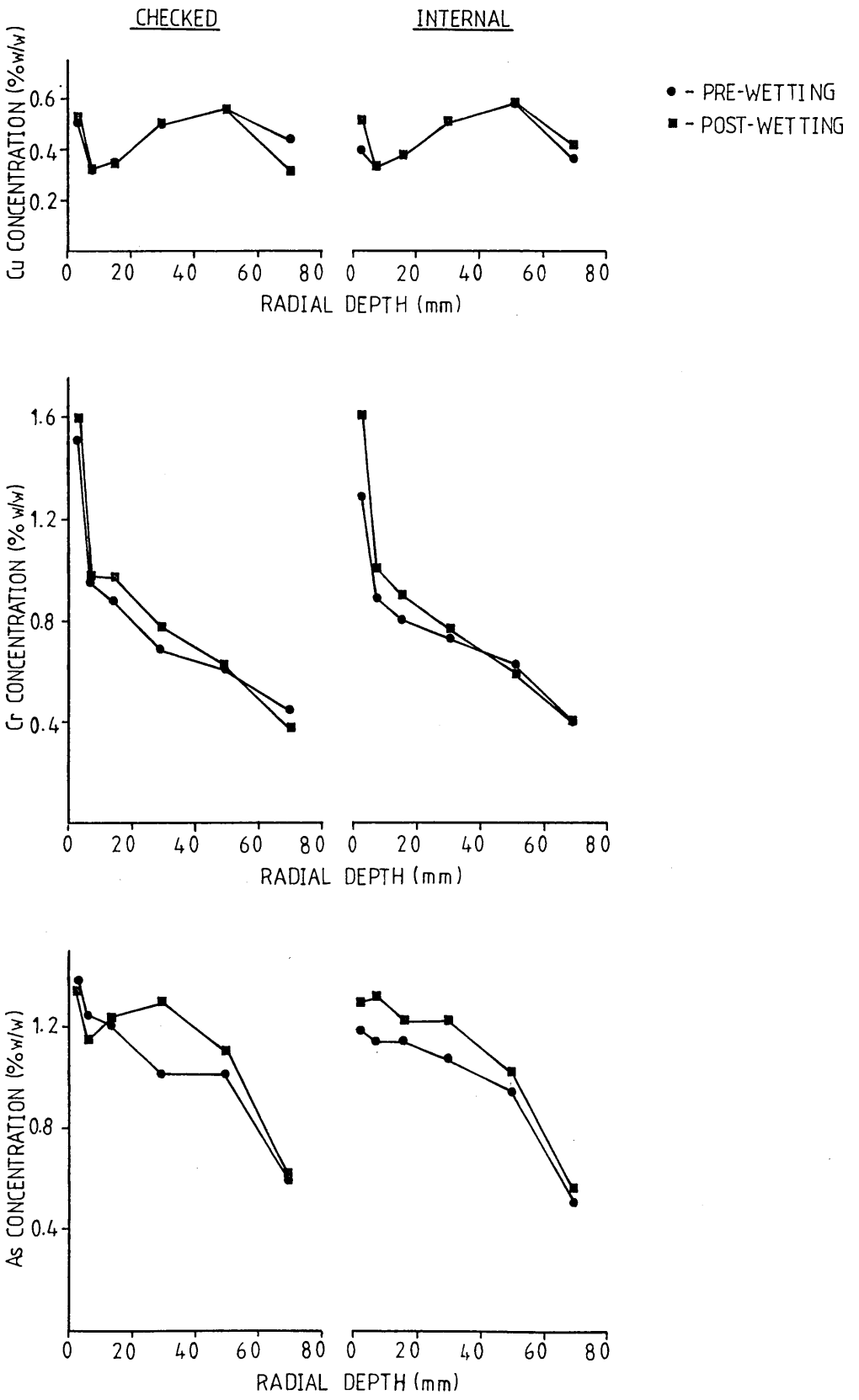


FIGURE 3.26: CORSICAN PINE

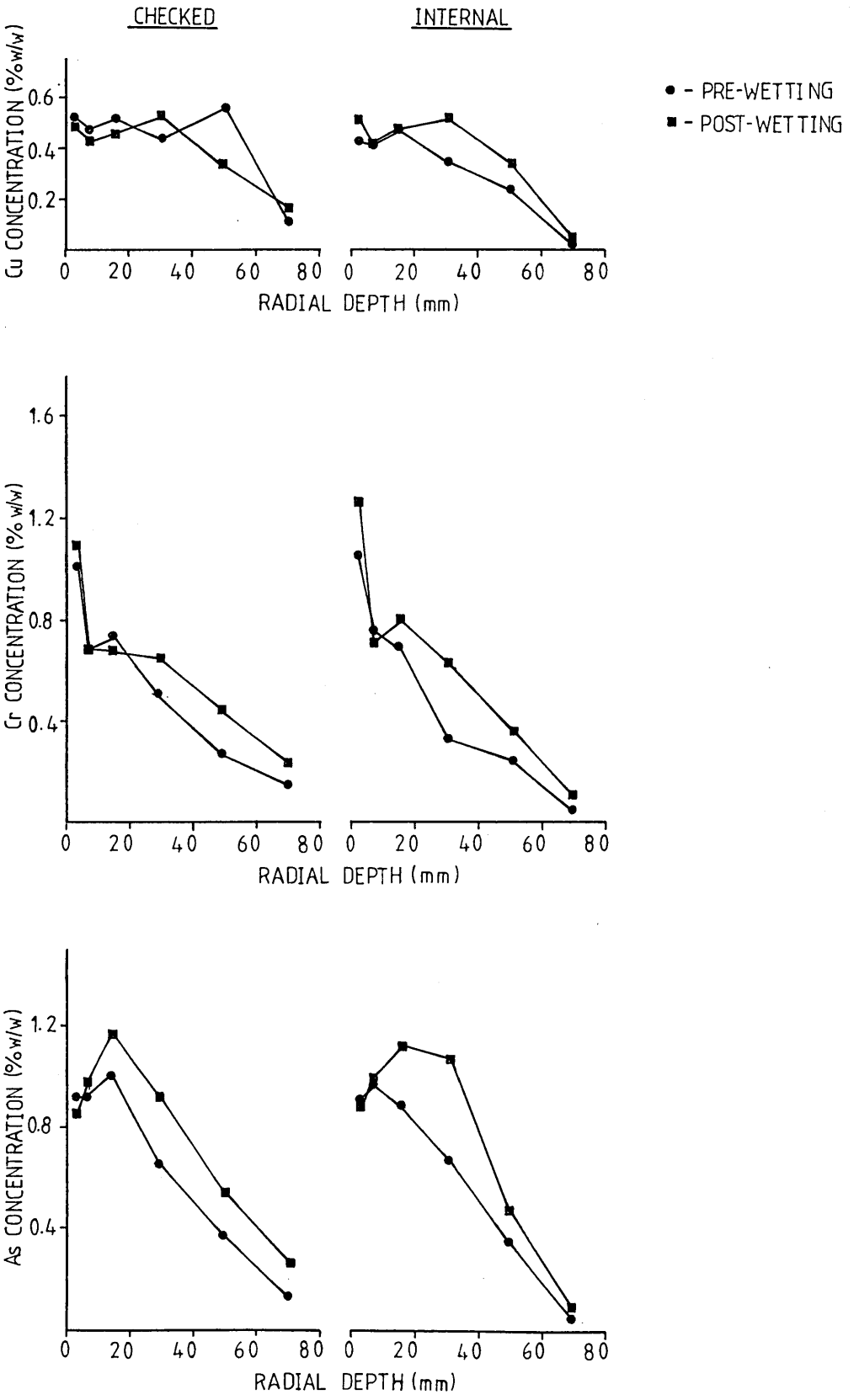


FIGURE 3.27: SCOTS PINE

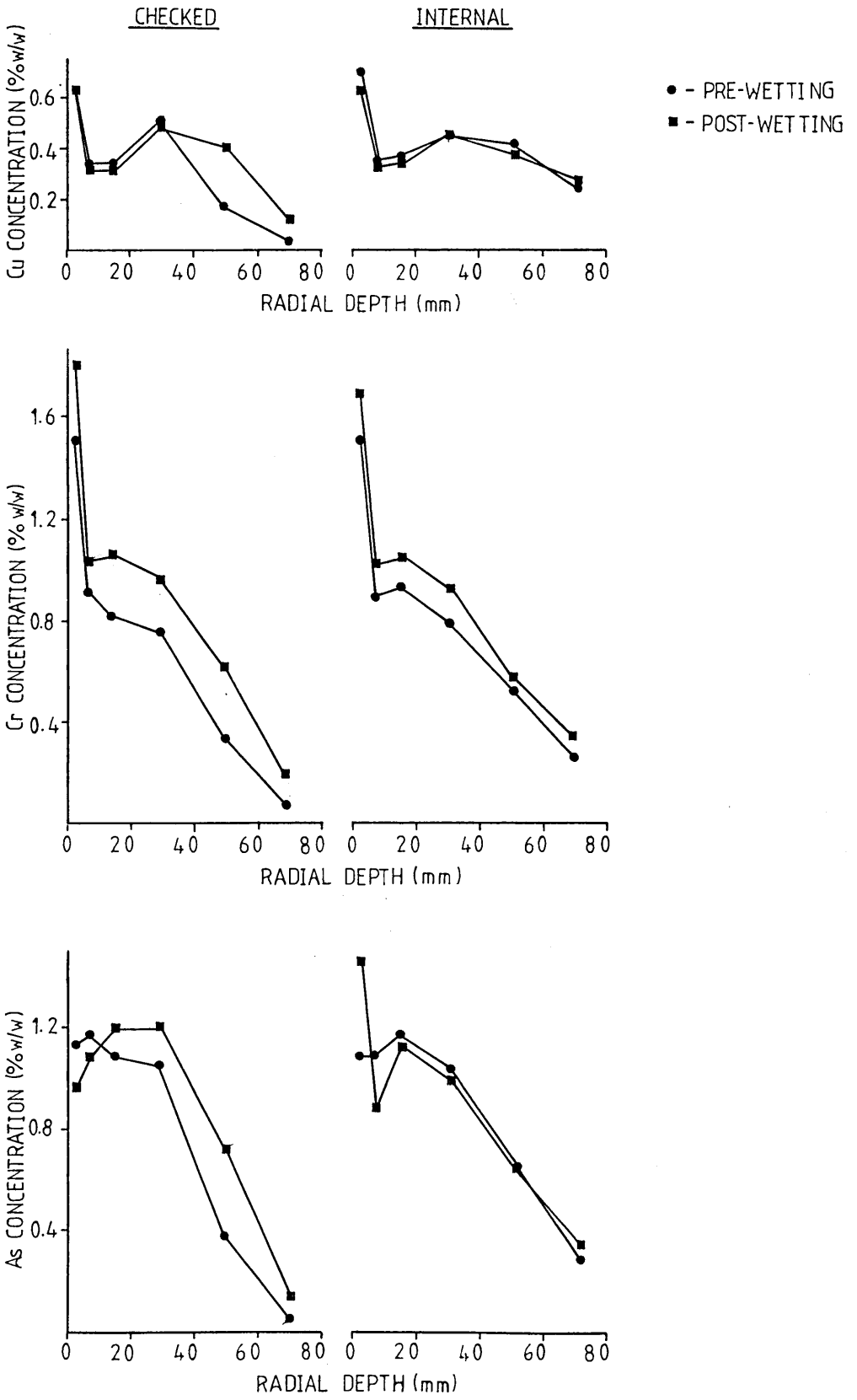


FIGURE 3.28: NORWAY SPRUCE

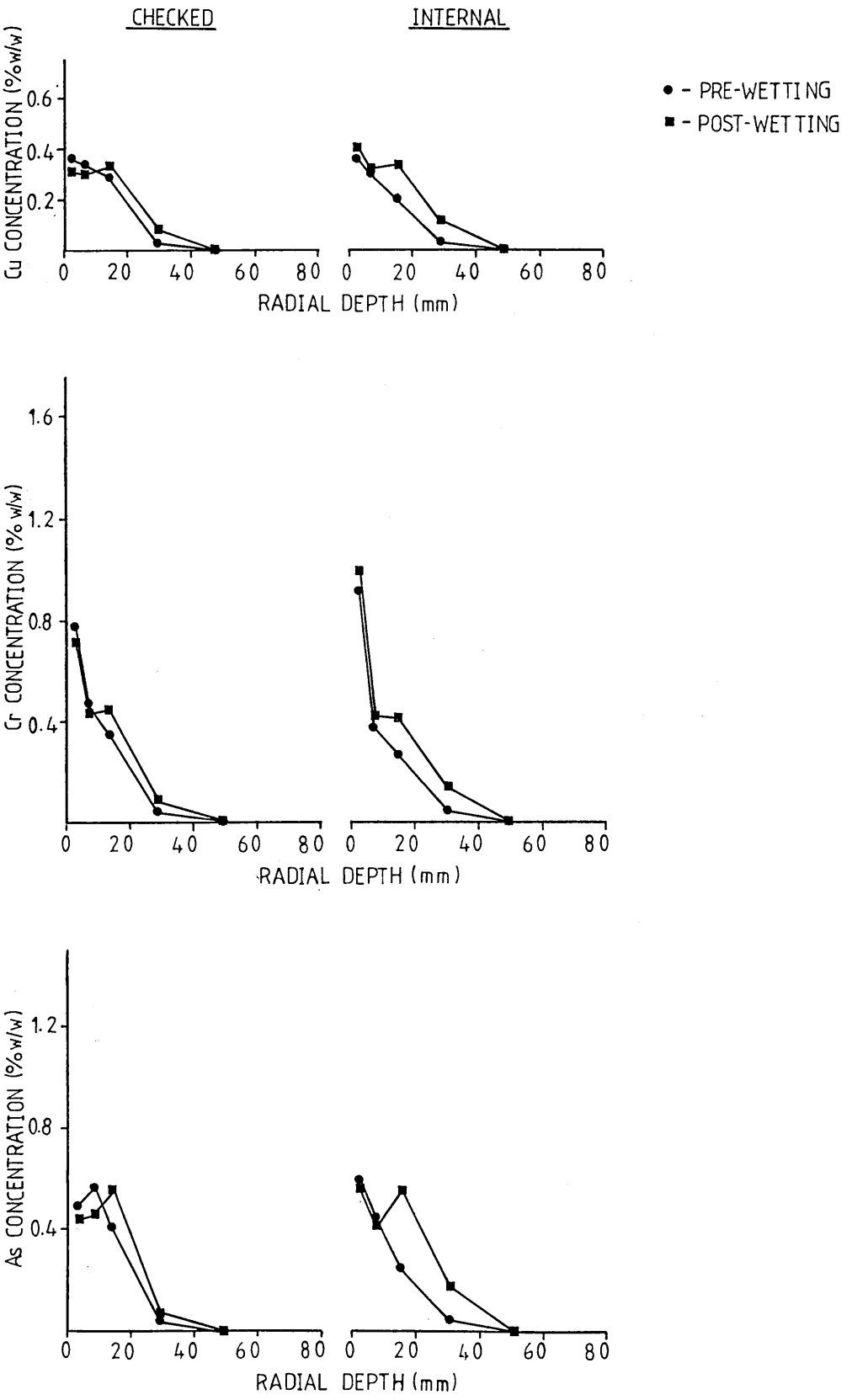


FIGURE 3.29: SITKA SPRUCE

individual wood sections and are presented as % weight/weight (metal/wood) in Table 3.16. It is obvious from the table of results that leaching of the preservative components had occurred but that concentrations were minimal in comparison to the preservative loadings in the wood sections (Figures 3.26 - 3.29) e.g. 0.5% copper was recorded at surfaces of Corsican pine pole sections (Figure 3.26) but only 0.00024% copper was recorded in the leach water.

There do not appear to be any major differences between the four wood species. Though Sitka spruce appeared to show greater losses of copper and chromium than the other three species, it must be noted that higher standard deviations were recorded in this species. The average time taken to reach 30% moisture content did vary considerably between the four species, with soaking time ranging from 10-12 hours for Corsican pine to 1 week for Sitka spruce. This confirmed the impermeable nature of Sitka spruce.

3.3.11.2. Effect of Soil Burial on CCA Levels and Distribution.

Radial profiles for copper, chromium and arsenic concentration in wood sections prior to soil burial and after 24 months burial, are presented in Figures 3.30 - 3.33. Each value represents the average of five replicate samples and are presented as % weight/weight (metal/wood). It is obvious from the graphs that in each of the four wood species, metal concentrations in wood sections before and after soil burial showed no major differences. Concentration profiles after 0 and

The legends below refer to Figures 3.30 - 3.33 on the following pages :-

Figure 3.30. Radial profiles of copper, chromium and arsenic concentration in Corsican pine pole sections prior to soil burial, and after 24 months soil burial in the accelerated decay system.

Figure 3.31. Radial profiles of copper, chromium and arsenic concentration in Scots pine pole sections prior to soil burial, and after 24 months soil burial in the accelerated decay system.

Figure 3.32. Radial profiles of copper, chromium and arsenic concentration in Norway spruce pole sections prior to soil burial, and after 24 months soil burial in the accelerated decay system.

Figure 3.33. Radial profiles of copper, chromium and arsenic concentration in Sitka spruce pole sections prior to soil burial, and after 24 months soil burial in the accelerated decay system.

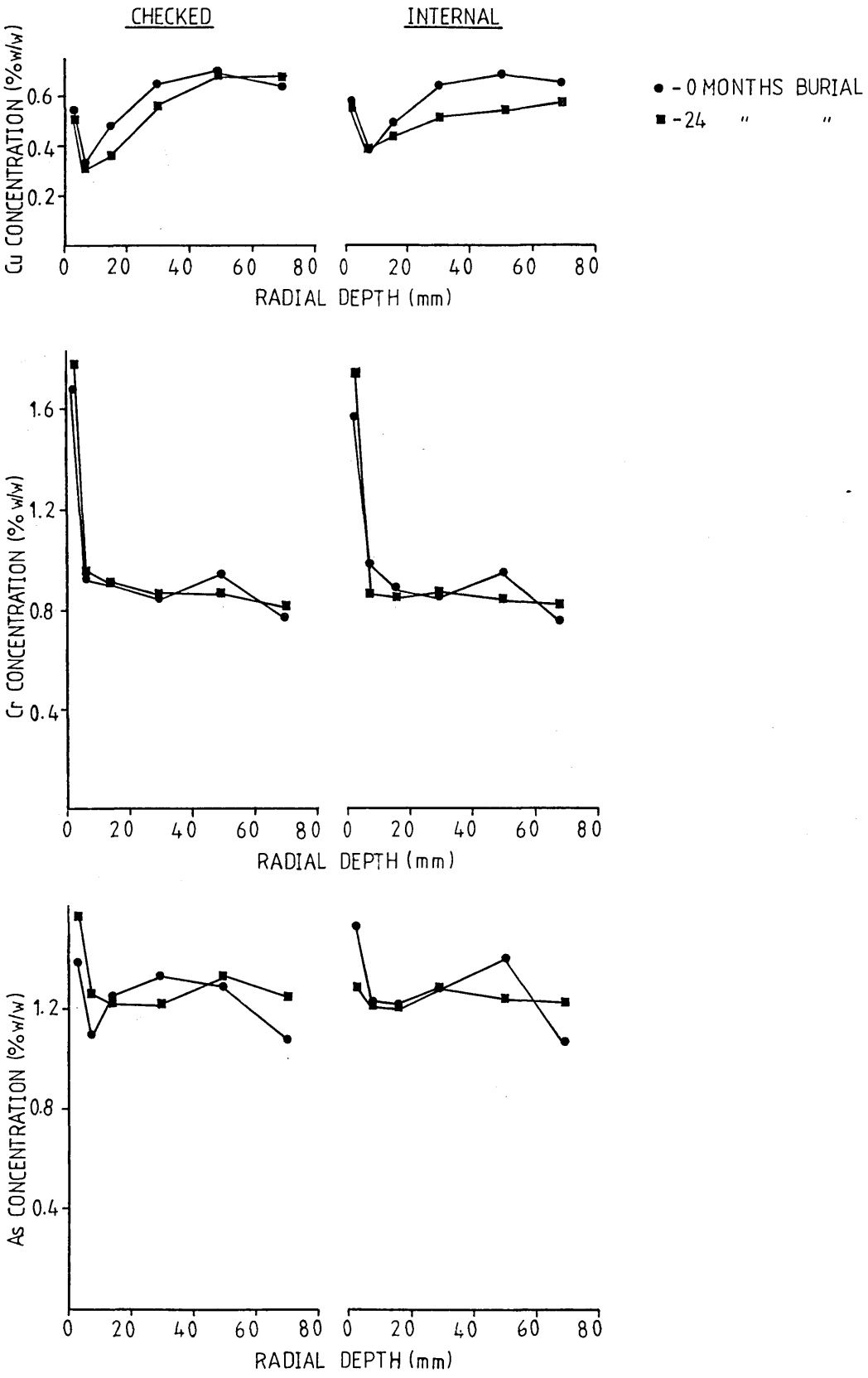


FIGURE 3.30: CORSICAN PINE

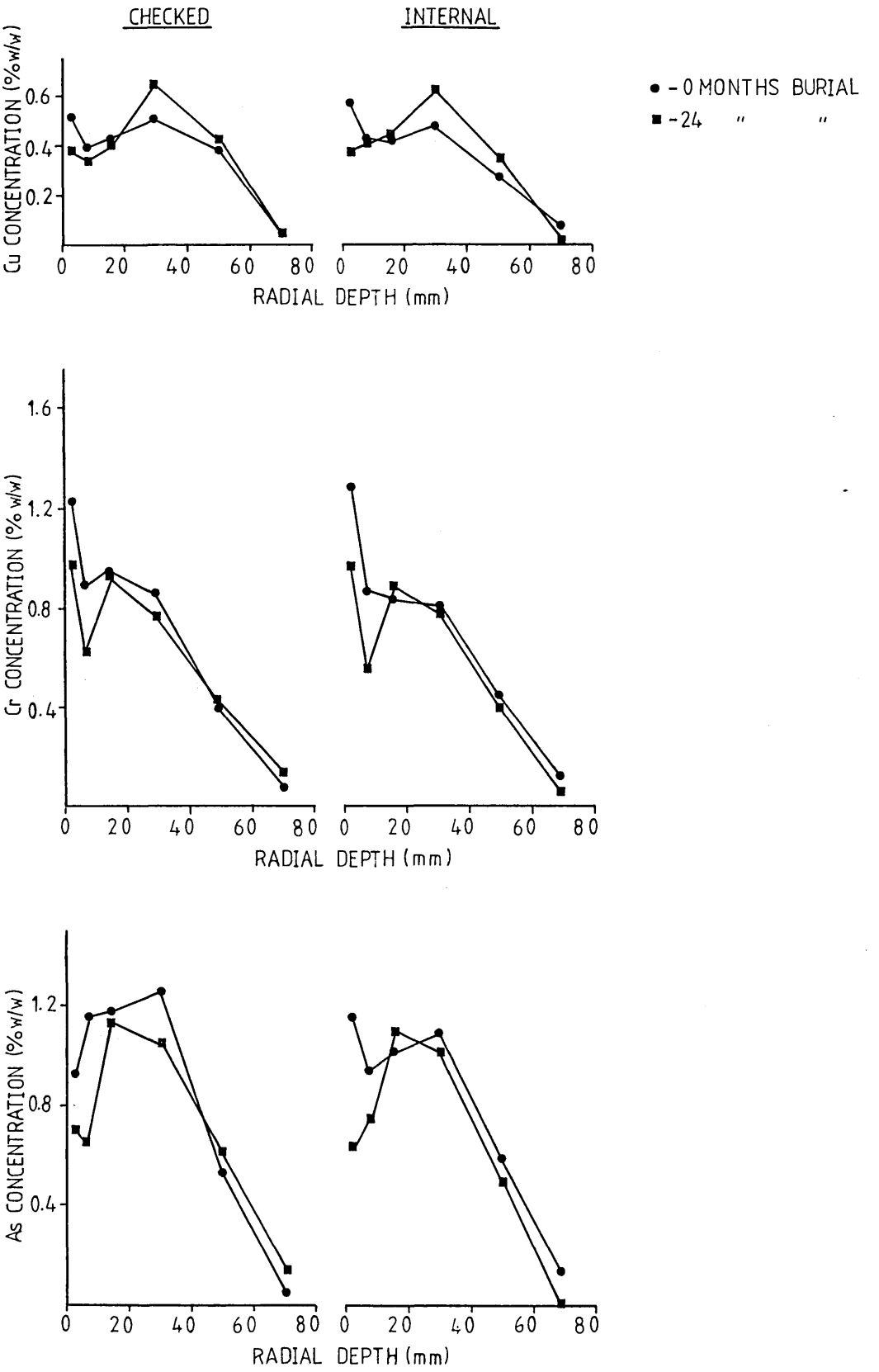


FIGURE 3.31: SCOTS PINE

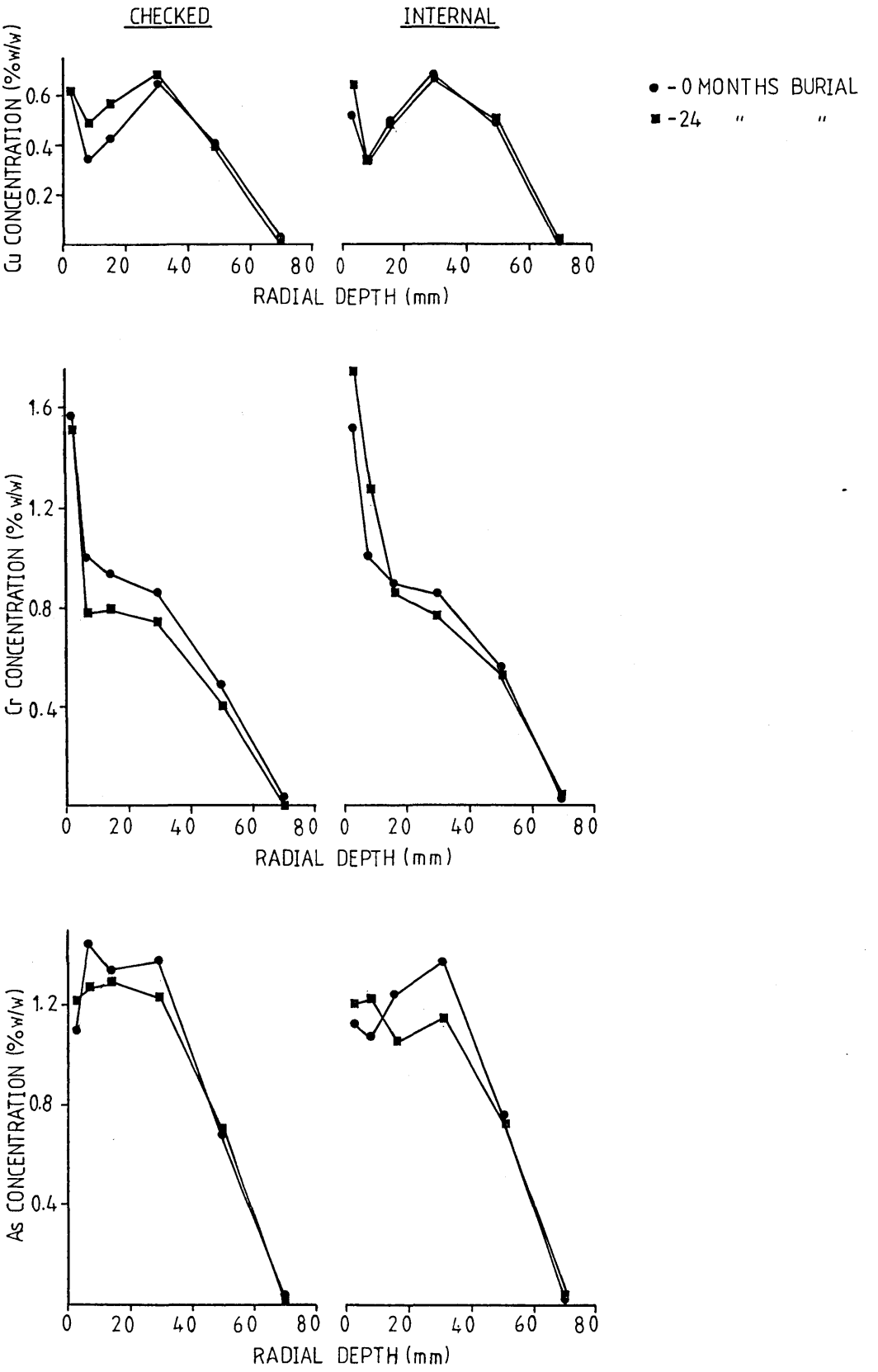


FIGURE 3.32: NORWAY SPRUCE

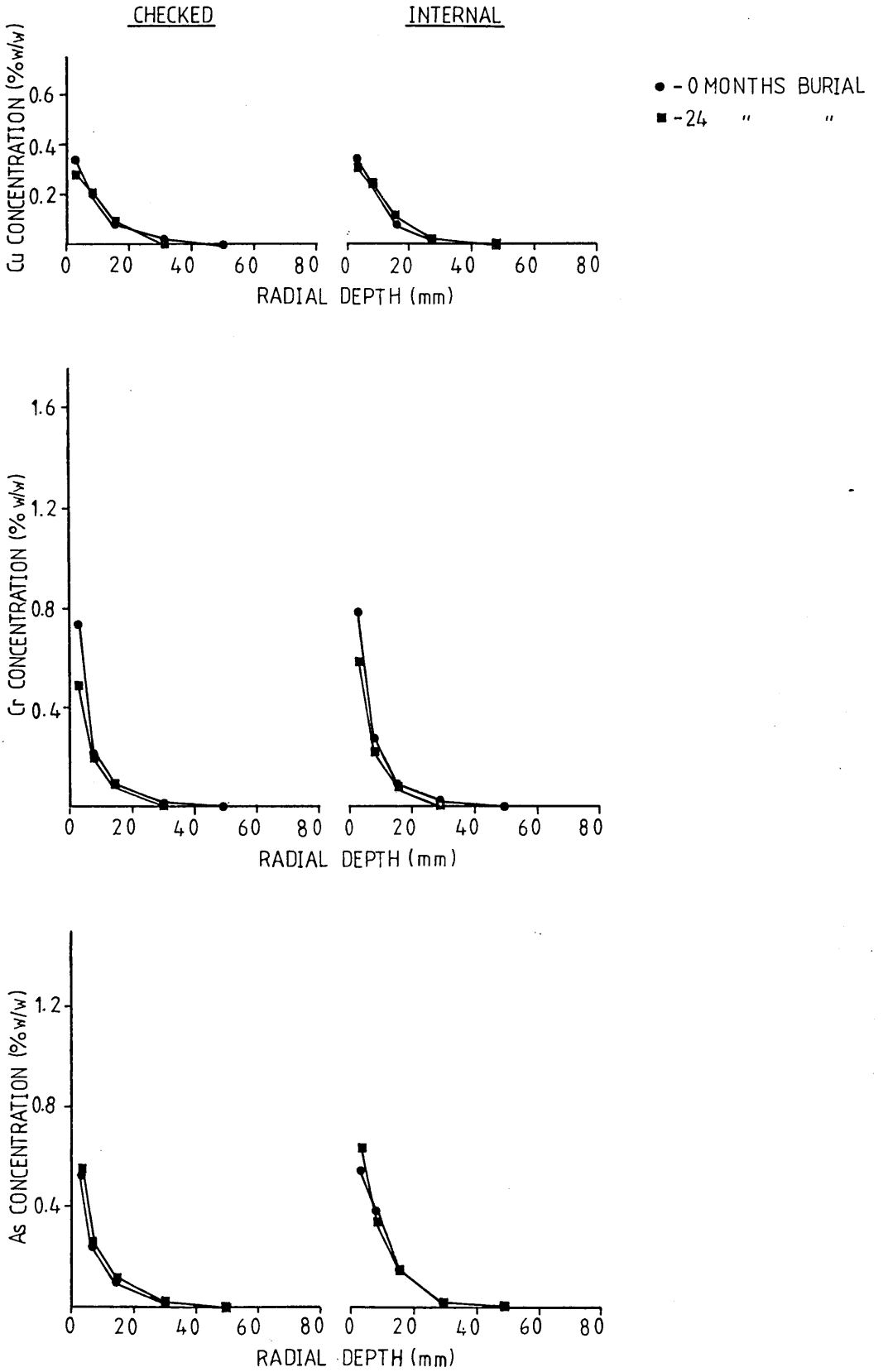


FIGURE 3.33: SITKA SPRUCE

24 months soil burial are shown to be very similar, and in the case of Sitka spruce to be almost identical (Figure 3.33). The only consistent difference observed is the slight surface depletion of copper, chromium and arsenic in the outer 10mm of Scots pine wood sections after 24 months burial.

3.3.11.3. CCA Analysis of Decayed Regions.

The concentration (% w/w of metal/wood) of copper, chromium and arsenic in wood samples removed from the decayed regions of wood sections are presented in Table 3.17. While samples were removed from a number of Scots pine and Norway and Sitka spruce sections no results are available for Corsican pine since decay pockets were not observed in this treated species.

The results indicate that in each of the three wood species, the three preservative components were present immediately adjacent to the decayed region, however, at the site of decay the preservative treatment was minimal or totally absent. Decay of the three species therefore occurs only in regions of the pole sections where copper, chromium and arsenic are absent or at extremely low concentrations.

3.3.12. CCA Analysis of Soil.

Soil sampled adjacent to CCA-treated wood sections at each sampling period i.e. 6, 12, 18 and 24 months, was examined for copper, chromium and arsenic content. Results for this analysis are presented in Table 3.18 and are recorded as mean values (and

Table 3.16. Concentration of copper, chromium and arsenic in water used to soak CCA-treated wood sections.

Wood Species	Time /days *	Metal Concentration/ %w/w x 10^{-3}		
		Copper	Chromium	Arsenic
Corsican pine	0.5	0.24 ± 0.052	0.31 ± 0.096	0.20 ± 0.240
Scots pine	2	0.42 ± 0.099	0.44 ± 0.071	0.16 ± 0.248
Norway spruce	3	0.32 ± 0.066	0.41 ± 0.110	0.26 ± 0.315
Sitka spruce	7	0.50 ± 0.329	0.53 ± 0.324	0.00 ± 0.000

* average soaking time required for wood sections to reach 30% moisture content.

Table 3.17. Concentration of copper, chromium and arsenic in wood samples showing visible signs of decay.

Wood Species	Sampling Location*	Metal Concentration / %w/w		
		Copper	Chromium	Arsenic
Scots pine	A	0.41 ± 0.074	0.44 ± 0.137	0.60 ± 0.157
	B	0.01 ± 0.011	0.01 ± 0.005	0.02 ± 0.008
Norway spruce	A	0.41 ± 0.156	0.45 ± 0.217	0.58 ± 0.318
	B	0.00 ± 0.008	0.01 ± 0.008	0.00 ± 0.003
Sitka spruce	A	0.18 ± 0.058	0.18 ± 0.053	0.24 ± 0.101
	B	0.02 ± 0.021	0.01 ± 0.015	0.02 ± 0.009

* A - sample removed immediately adjacent to decayed region (towards outer surface).
B - sample removed from decayed region.

Table 3.18. Concentration of copper, chromium and arsenic in soil sampled at the surface and 100mm from CCA-treated sections of the four wood species.

Sample Time/ months	Metal Concentration / ug/g soil					
	Copper		Chromium		Arsenic	
	Surface	100mm	Surface	100mm	Surface	100mm
Corsican pine						
6	58.9±15.0	44.4±4.7	37.0±4.3	31.9±1.3	55.2±29.4	38.8±21.5
12	63.7± 0.4	48.6±3.0	38.2±3.3	32.8±2.1	43.0±26.3	81.8±18.4
18	109.5±54 8	50.2±4.9	41.2±5.6	32.6±2.2	80.9±50.6	82.8±85.8
24	97.2±19.2	47.3±1.6	39.9±5.4	32.9±1.0	60.0±29.6	21.5± 6.3
Scots pine						
6	65.7± 6.6	47.4±2.5	39.4±4.2	32.4±1.5	64.6± 7.2	62.3±17.8
12	73.9±15.6	43.0±1.9	36.1±3.3	31.4±1.3	96.9±45.1	37.1±23.8
18	98.0±13.4	48.6±2.9	37.0±0.9	33.8±2.4	82.8±57.3	79.2±35.8
24	66.3±13.6	47.5±1.7	39.7±8.9	32.2±1.6	73.2±17.2	13.4±10.0
Norway spruce						
6	54.2± 5.1	44.3±2.4	37.8±3.4	31.5±0.6	39.4±23.8	47.4±47.4
12	65.2±14.2	47.4±5.8	36.6±3.6	31.0±3.1	105.1±49.7	55.0±12.6
18	65.3±17.4	50.2±2.7	38.8±3.4	29.2±2.8	69.4±22.6	87.3±61.9
24	55.8± 4.6	46.6±3.8	33.9±1.8	33.2±2.4	61.8±40.6	27.8±23.5
Sitka spruce						
6	50.9± 2.6	48.2±8.4	34.4±3.7	33.0±1.2	47.3±24.9	47.4±23.4
12	59.4± 3.3	47.4±1.3	35.8±0.8	32.3±1.7	82.1±37.3	80.7±52.2
18	72.1± 5.1	49.0±4.5	34.0±1.0	30.5±0.6	65.7±26.6	53.9±54.2
24	61.2±19.0	55.6±1.5	31.4±2.4	34.7±1.9	50.0±16.1	103.2±75.1

standard deviations) for three replicate samples.

In general, Table 3.18 shows that increased levels of copper were present in soil sampled adjacent to CCA-treated sections of all four wood species. In the case of chromium, surface soil samples contained slightly higher levels than samples removed at a distance of 100mm, however, these raised levels were not as obvious as in copper measurements. Arsenic contents of soils were found to vary considerably, resulting in very high standard deviations which made interpretation of results difficult.

Statistical testing of the data by analysis of variance confirmed the above observations, showing significant increases ($p < 0.0005$) in copper and chromium in surface samples compared with background levels, whilst no significant differences ($p > 0.05$) were observed for arsenic measurements. The increased copper contents were found to exist in all four wood species however, surface and background of chromium levels near Sitka spruce sections were not found to be significantly different.

To investigate the effect of burial time on the leaching of preservative components, metal concentrations at each of the four time periods were compared statistically by analysis of variance. While a significant difference ($p < 0.005$) was found for copper levels in surface soil samples at the four time periods, no significant difference ($p > 0.05$) was observed for chromium or arsenic. From Table 3.18 it is apparent that the effect of time on copper concentration was consistent for all four wood species. Comparing the four time periods, shows copper concentration to increase steadily until the 18 month sampling period, however, after 24 months, copper in surface soil samples showed a small,

but consistent drop in concentration.

To determine if the leaching of CCA components from wood sections to the surrounding soil had any significant effect on the level of soil microbial activity i.e. dehydrogenase activity, the correlation factor was calculated. Comparison of copper, chromium and arsenic concentrations with their corresponding dehydrogenase measurements confirmed a significant negative correlation for copper ($r = -0.459$) , i.e. as copper concentration increased dehydrogenase activity decreased. No significant correlation was recorded for either chromium or arsenic.

3.4. DISCUSSION.

3.4.1. Control of Accelerated Decay Conditions.

Conditions of temperature, humidity and soil moisture within the accelerated decay system were strictly controlled throughout the incubation period to provide an ideal environment for the decay of softwood pole sections. Once the desired conditions were achieved, the environment was closely monitored and maintained at these starting levels using the control methods described in section 3.2.1.

Temperature and humidity levels within the room were maintained at 26-28.5^{o}C and 75-85% respectively, and the use of perspex sheets over the soil beds ensured that the humidity around the wood sections was constantly controlled at 95-100%. Soil moisture levels were also closely controlled and showed little variation over the operational period with no problems of surface drying or waterlogging, as reported by Vinden et al (1982) during their preliminary studies in setting up a soil-bed system. The inclusion of a profiled soil system to aid drainage, and the use of perspex covers to reduce surface drying provided ideal control conditions for soil moisture levels. Determination of soil moisture contents during dehydrogenase assays confirmed levels of around 20% (~100% WHC) throughout the duration of the project.

The repeated burial of small lime woodblocks in each of the soil beds confirmed that conditions within the test system were conducive to soft rot decay throughout the duration of the

project. Although the pole sections under test were softwood species, it was decided to use lime woodblocks for rapid soil viability studies since previous workers at this laboratory have shown hardwoods to decay more readily than softwoods under similar soil burial conditions (Briscoe, 1987; Green, 1988). Soil viability was also confirmed by exposure of untreated pole sections of each of the four test species, which were shown to have suffered external soft rot decay to depths of up to 12mm within the first six months of soil burial.

The use of a mycelial spray to inoculate wood sections with basidiomycete fungi was developed for this project. Viability of the spray was initially tested on agar plates and later confirmed on wood sections exposed within the accelerated decay system. Visual examination of the test sections showed extensive internal brown rot decay of many of the spruce sections, and was later confirmed (by SDS-PAGE analysis of fungal isolates) to be caused by *G. trabeum*, a component of the initial spray inoculum.

The accelerated decay system was therefore shown to be suitable for providing conditions necessary for both soft rot and basidiomycete decay. Environmental conditions were adequately controlled and no major problems e.g. waterlogging or excessive drying of soil, were encountered throughout the duration of the project.

3.4.2. Permanence of CCA Components.

In order to represent the field exposed poles as closely as possible, wood sections exposed within the accelerated decay system were cut from full size poles commercially treated with a 1.8% CCA Type II solution by pressurised sap-displacement i.e. identical treatment to the field poles. Analysis of copper, chromium and arsenic distribution in radial samples removed from the pole sections (Figures 3.30-3.33) confirmed the similar levels of treatment achieved in field and laboratory exposed test material i.e. gradient of metal concentration decreasing from pole surface to centre, and an internal peak in copper concentration in all species except Sitka spruce. The close similarities in initial levels and distribution of preservative elements in samples exposed to the two test conditions would therefore allow a much clearer interpretation of results from the accelerated decay system as a model for poles exposed in the field situation.

Wetting of the wood sections prior to soil burial was found to have a very small effect on the distribution of copper, chromium and arsenic (Figures 3.26-3.29), with slight re-distribution of the preservative components towards pole centres. Levels and distribution of the three metals remained similar to those of the field poles therefore this slight movement was not regarded as affecting the overall treatment of the wood. Analysis of metal concentration in the water used to soak the sections, showed very small amounts of copper, chromium and arsenic had leached from the wood sections (Table 3.16). Of

the three metals, copper losses were found to be the greatest in comparison to metal loadings in the wood, however, in all cases its concentration in the water was less than 1/1000 of the concentration in the outer wood surfaces, e.g. in Corsican pine, 0.5% copper was recorded at surfaces of the wood sections (Figure 3.26), whereas only 0.00024% copper was leached to the water (Table 3.16).

Of the four wood species, leaching of copper and chromium was slightly higher in Sitka spruce sections (Table 3.16), although this species had significantly lower levels of CCA treatment than the other three wood species. This result correlates well with the significant increase in losses of chromium from poles of this species in field exposed poles (Table 2.8), and to the increased rate of leaching in wood treated to lower CCA retentions reported by Fahlstrom et al (1967), Dahlgren (1975) and Briscoe (1987). Increased losses in this species may also be a consequence of the much longer soaking time required for the wood sections to reach 30% moisture content i.e. 7 days for Sitka spruce compared with about 12 hours for Corsican pine.

Burial of the pole sections in the accelerated decay system, resulted in no apparent changes in the preservative components within the four wood species (Figures 3.30-3.33). Significant increases in copper and chromium content of soils adjacent to treated sections of the four wood species were however, recorded (Table 3.18). Compared with metal levels recorded in soil adjacent to the field poles (Table 2.8), copper and chromium losses were much lower in the accelerated decay system, and although significantly higher chromium losses occurred from Sitka

spruce poles in the field, no significant increase in chromium levels adjacent to Sitka spruce wood sections in the accelerated decay system were recorded. This reduced leaching of preservative components to the surrounding soil may have resulted from the initial soaking procedure when small amounts of copper, chromium and arsenic were leached from the wood thereby reducing further losses during soil burial. However, it may also have been a consequence of the lack of precipitation in the laboratory system, and therefore highlights one limitation of accelerated decay systems in representing the overall environmental conditions experienced in the field. This problem was also encountered by Hedley (1980), who suggested that wood specimens should be pre-weathered before exposure in a fungus cellar, and that rainfall simulation could be incorporated into the design of the cellars.

3.4.3. Soft Rot Decay.

Examination of the extent of soft rot decay in control and CCA-treated wood sections showed extensive decay development on the outer surfaces of control sections but total protection against soft rot of the outer surfaces of the treated sections. Although soft rot decay was examined directly by pilodyn (Tables 3.4 & 3.5) and microscopic techniques (Figure 3.8), changes in microbial activity as measured by a dehydrogenase assay of soil adjacent to the wood (Tables 3.2 & 3.3), was also found to correlate well with decay development.

The enzyme assay used to measure changes in soil activity

was based on that of Casida et al (1964) and modified by Mowe (1983) for use on small soil samples. The enzymes measured were dehydrogenases which are produced by soil organisms to catalyse the transfer of hydrogen from organic substances to molecular oxygen (Ruhling and Tyler, 1973). The assay used in this project however, is based on the assumption that in the absence of oxygen, triphenyltetrazolium chloride (TTC) acts quantitatively as the terminal hydrogen acceptor resulting in the formation of red triphenyltetrazolium formazan (TTF), which may then be measured colorimetrically (Benefield et al, 1977). The TTC assay has previously been used at this laboratory (Mowe, 1983; Green, 1988) and although it was shown to be useful in determining the effect of wood species and preservative treatment on microbial activity of small buried woodblocks, it is important to note that the assay does not give absolute levels of microbial respiration (Howard, 1972; Benefield et al, 1977). This project however, indicates that the technique can also be used as a valuable method of measuring increased microbial activity at the wood/soil interface which is associated with the early decay of larger dimension timbers which are more representative of field samples.

Dehydrogenase measurements in soil adjacent to control wood sections were consistently found to be higher than background levels (Tables 3.2 and 3.3). These increased levels were accompanied by soft rot decay of the outer surfaces of the wood sections, as confirmed by pilodyn (Tables 3.4 and 3.5) and microscopic studies (Figure 3.8), and occurred irrespective of wood species. This type of biotic connection between wood and soil during soft rot decay was previously reported by King et al

(1980). Although measurements of dehydrogenase in soil at the wood surface remained higher than background levels over the entire 24 months of soil burial, increasing burial time was found to result in a significant decrease in soil activity from the elevated levels recorded after 6 months burial. Since the extent and depth of soft rot decay in the control sections was generally found to increase with increasing soil exposure (Figure 3.8), it is possible that as the decay organisms have invaded deeper into the wood, the active microbial biomass and associated dehydrogenase activity would decrease in the soil adjacent to the wood surface.

Although CCA-treated sections were adequately protected against decay development, an initial increase in microbial activity was also recorded in soil adjacent to their surfaces after 6 months burial (Tables 3.2 and 3.3). A similar initial increase in dehydrogenase activity after only 3 weeks soil burial was recorded in small woodblocks treated with CCA (Green, 1988). It has been suggested that on soil burial, soluble wood nutrients, including nitrogen and carbohydrates, rapidly diffuse into the surrounding soil and induce some microbial germination (Smith, 1980). It was indeed reported by Baruah and Mishra (1984) that dehydrogenase levels showed good correlation with carbon and nitrogen content in soil. Mowe (1983) also proposed that volatiles released from the wood to the adjacent soil may stimulate fungal growth thereby increasing microbial activity within the soil.

After this initial increase in dehydrogenase activity, and after a further 6 months burial, microbial action in soil

adjacent to treated sections returned to background levels, indicating that the initial stimulatory phase was complete. However, on continued exposure (18 and 24 months), soil activity adjacent to the treated sections fell to slightly below background levels, suggesting that the presence of the CCA-treated material was exerting a deleterious effect on microbial activity in the soil.

Analysis of soil for the presence of CCA components, showed increased levels of copper adjacent to treated sections of all four wood species, and increased chromium levels adjacent to all species except Sitka spruce (Table 3.18). These raised soil metal levels were recorded at each sampling period, and in the case of copper, showed a steady increase until 18 months after which a small but consistent drop was recorded. A significant correlation ($r = -0.459$) was found between copper concentration and dehydrogenase levels in soil adjacent to the four treated wood species, and may in part account for the protection of the treated sections which was recorded. The presence of copper and chromium would inevitably have an effect on the microbial population of the soil and might be expected to reduce the diversity of species present and favour preservative tolerant species. Selection of preservative tolerant species at the wood/soil interface has been previously reported around CCA-treated (Murphy and Dickinson, 1982) and fluo-silicate treated stakes (Clubbe, 1983), and a positive correlation between the copper content of soil and the number of copper tolerant fungi isolated, was reported by Yamamoto et al (1985). In this present study, the selection of such tolerant species, if it

occurred, did not result in decay of the outer treated surfaces within the burial period of the experiment.

To establish whether the increased soil activity adjacent to both control and treated sections was accompanied by decay development of their outer surfaces, pilodyn measurements were recorded for the curved surfaces of sections uplifted at each sampling period. The pilodyn has been used in the past by many workers to measure soft rot development in salt-treated poles under field conditions (Leightley, 1981, 1982, 1986a; Friis-Hansen, 1980) and was successfully used in this project to monitor the increasing surface decay of untreated control sections during soil burial (Tables 3.4 and 3.5). The sensitivity of the instrument was however, found to limit its usefulness for decay monitoring. The instrument was not able to detect differences in extent of decay between different wood species, and it reached a threshold level after which continued soft rot to deeper depths produced no further change in pilodyn readings i.e. after 18 months soil burial.

Microscopic analysis of the depth and severity of soft rot decay in untreated sections showed Corsican pine to be the worst affected species (Table 3.8), however, this effect was not obvious from the results measured by pilodyn. Previous workers have found the 6 Joule pilodyn to provide the required sensitivity in detecting external decay of salt-treated poles (Friis-Hansen, 1980; Leightley, 1981, 1982). Leightley (1986a) also found high correlation between pilodyn measurements and the extent of soft rot decay (determined microscopically) in CCA-treated eucalypt poles. It is therefore possible that the

greater penetrating power of a 6 or 12 Joule pilodyn (a 2 Joule instrument was used here) could have increased the information obtained from this study.

A major disadvantage of the pilodyn is the reported adverse effect of moisture content on recorded readings (Hoffmeyer, 1978), however, in this study the effect of moisture was not found to restrict the assessment of soft rot decay. It was reported by Friis-Hansen (1980) that moisture contents above fibre saturation point had a negligible effect on pilodyn readings. Since pole sections exposed in the accelerated decay system were all around 30% moisture content prior to soil burial and were maintained at or above this level throughout operation of the system (Figures 3.11-3.14), increases in pilodyn readings after soil burial were regarded as indicating soft rot decay and this was later confirmed by microscopic analysis.

Although pilodyn readings indicated progressive surface decay of untreated pole sections, no such effect was observed in CCA-treated sections. Pilodyn measurements showed no increase over the 24 month burial period (Tables 3.4 and 3.5), and microscopic studies later confirmed total protection of these sections against soft rot. The surface hardening effect of CCA treatment reported by Jonnsson et al (1989) was noted in the pine pole sections, where pilodyn readings for unburied CCA-treated sections were lower than the untreated controls. This hardening effect, which is thought to result from the formation of rigid polymeric structures during fixation reactions of chromium with lignin and cellulose (Pizzi, 1979, 1981) was not observed in the spruce species. Although this may be a result of inter-pole and

inter-section variation in wood density, it may also be a consequence of differences in moisture distribution in the four wood species. Due to the impermeable nature of the untreated spruce species, moisture uptake during the wetting procedure may have been limited to the outer wood surfaces of the sections, leaving a relatively dry centre which may have limited pilodyn penetration. The more permeable pine species could be expected to have a more even radial moisture distribution which might result in deeper pilodyn penetration.

Soft rot decay of wood is widely known to occur by direct soil contact, consequently pilodyn readings for below ground regions of the untreated pole sections showed progressive decay development with increasing burial time. It is interesting to note however, that after an initial lag period (12 months), soft rot decay spread to the upper regions of the sections, as indicated by increased pilodyn readings (Tables 3.4 and 3.5). Soft rot decay of these above ground regions increased in severity until after 18 months burial, when above and below ground pilodyn measurements were similar. Progression of decay in Sitka spruce sections was noticably slower both below and above ground and consequently, after 24 months burial, pilodyn readings for this species were continuing to rise.

Pilodyn measurements were also attempted on the checked surfaces of untreated and CCA-treated pole sections in an effort to assess the extent of internal decay. Due to the difficulty in standardising sampling to either latewood or earlywood, pilodyn penetration was found to be highly variable (Tables 3.6 and 3.7) and impossible to interpret meaningfully. Pilodyn is therefore

not recommended for detection of decay of checked surfaces.

In order to confirm pilodyn results and to define the real extent of soft rot decay, microscopic analysis of small wood samples removed at increasing radial depths was undertaken using a modification of the method described by Anagnost (1987). Untreated control sections were found to have suffered extensive decay of their curved surfaces which became more invasive with increasing burial time (Table 3.8), reinforcing the assessment of decay recorded using pilodyn. Depth and severity of decay of the wood sections was shown to increase throughout the soil burial period, resulting in the characteristic profiles shown in Figure 3.8.

The severity of soft rot decay was shown to be dependent on wood species, with Corsican pine suffering very severe decay and Sitka spruce being the least affected. Extensive decay of Corsican pine sections after 12 months burial (Figure 3.8, and in Bruce et al, 1991) show very high soft rot decay indices recorded at greater radial depths compared with the other three wood species. This species effect was also observed by Evans et al (1988) during soil burial of small sapwood blocks of UK grown softwoods sap-displaced with water.

Nutrient status of the four wood species may largely account for their variable susceptibility to soft rot decay since soluble nitrogen content has previously been found to accelerate soft rot decay in pine and spruce (Oxley et al, 1976). Nitrogen content of the outer sapwood of UK grown Corsican pine was recorded by Waite (1977, in Bruce et al, 1991) as 0.18% and was significantly higher than values reported by King et al (1976) for UK grown

Scots pine (0.11%) and Sitka spruce (0.07%). If nitrogen contents of pole sections used in this study can be assumed to be similar to these reported values, they may account for the species variability in soft rot severity observed here.

Another factor which may account for the species effect on severity of decay, is the differing moisture profiles recorded in sections of the individual wood species. Soft rot organisms are reported as requiring high wood moisture contents (King, 1979). Figures 3.11 - 3.14 show the wide variabilty in moisture uptake of the pines and spruces, indicating that the pine species wet up more readily than the spruces. The refractory nature of the spruces, particularly Sitka spruce, is again reflected in low moisture uptake (Figures 3.13 and 3.14) and indicated previously by low preservative uptake (Figures 3.32 and 3.33). Indeed, when the untreated pole sections were initially wet up to 30% moisture content prior to burial, untreated Corsican pine reached the desired moisture level within one hour while Sitka spruce required several hours to days.

On treatment of the wood with CCA, none of the four wood species suffered soft rot decay of their curved surfaces, indicating that the CCA was providing adequate protection against this type of decay hazard. Small pockets of soft rot decay were however, found on the internal checked surfaces of treated sections of all four wood species (Table 3.9). These pockets of decay were almost entirely found in the untreated core of the pole sections, near the border between treated sapwood and untreated heartwood, except for one Sitka spruce section where soft rot cavitation was recorded within the CCA-treated region.

This one incidence of decay of treated material did however, occur at the innermost region of the treated band where copper concentration was as low as 0.02% (Figure 3.33). Such internal soft rot has been reported by Friis-Hansen and Lundstrom (1989) in CCA-treated Scots pine poles in service in Sweden for more than twenty years.

In contrast to decay development in untreated control sections, the greatest extent of decay of internal checked faces in CCA-treated sections was recorded in Sitka spruce (Table 3.9). This result is due entirely to poor retention and penetration of CCA salts recorded in this species (Figure 3.33) and compaction of soil in the open checks. If this species is to be pursued as a viable commercial product, improvement in the depth of CCA penetration and/or reduction in the extent of checking must be achieved. This problem was also encountered in the field poles where low CCA penetration (Figure 2.9) and extensive checking (Table 2.9) resulted in colonisation by basidiomycete decay fungi after only four years field exposure (Table 2.10).

3.4.4. Basidiomycete Decay.

In contrast to the lack of soft rot decay development in CCA-treated pole sections, extensive internal basidiomycete decay was observed in sections of some CCA-treated species which had been sprayed with the mycelial inoculum. Visual examination of all sections exposed in the basidiomycete test system showed a pronounced species effect, with the spruces, particularly Sitka spruce, suffering extensive brown rot decay whilst the pines

showed little or no internal decay development.

Direct inoculation of the open checks with *G. trabeum* and *T. versicolor* in the form of a mycelial spray, resulted in colonisation and decay solely by the brown rot organism. This occurred irrespective of the fact that the two organisms were compatible during agar interaction studies, and that *T. versicolor* was the faster growing organism on malt extract agar. Development of brown rot decay in preference to white rot, was not unexpected since it has been previously suggested that softwood species are more prone to decay by brown rot agents, while hardwood species are more commonly affected by white rot fungi (Nilsson and Daniel, 1987). The greater ability of brown rot fungi to degrade softwood hemicellulose (Lewis, 1976) and the effect of high lignin content (Highley, 1976) and lignin type (Highley, 1987), have been reported as possible reasons for such host preference.

Characterisation of fungal isolates from decayed regions of the pole sections confirmed the presence of *G. trabeum* after comparison of their protein profiles with those of reference species by SDS-PAGE. This technique has been recently reported for distinguishing between isolates, strains and species of wood decay basidiomycetes (Vigrow et al., 1989) and can be considered a useful addition to the standard microbiological methods of Nobles (1964) and Stalpers (1978) for identification of organisms isolated from decayed wood.

Visual decay index results for CCA-treated pole sections sprayed with the fungal inoculum (Table 3.11) confirm the species variability in extent of decay development, with the severity of

decay decreasing from Sitka spruce > Norway spruce > Scots pine > Corsican pine. As previously mentioned (section 3.4.2), the sapwood of Corsican pine has been reported to contain much higher nitrogen levels (Waite, 1977, in Bruce et al., 1991) than the other three test species which may encourage decay development. Indeed, this species is known to readily decay during pre-treatment seasoning periods (Morrell et al., 1987; Zahora and Dickinson, 1989). Chemical analysis of samples from this species (Figure 3.30) do however, indicate very high levels of copper, chromium and arsenic to radial depths of at least 80mm. Excellent preservative treatment of Corsican pine has therefore prevented the development of basidiomycete decay.

Although Scots pine and Norway spruce pole sections showed similar depths of CCA penetration (Figures 3.31 and 3.32), Scots pine suffered a much lesser extent of internal decay than the spruce species (Table 3.11). After 18 months soil burial, a visual decay index of 1.1 was recorded for the untreated portions of Scots pine sections (Table 3.11). This was primarily due to surface rot, with little evidence of decay penetrating inwards from the surface, as shown by a visual decay index of 0 for the cross-sections of these samples. Increased decay resistance of Scots pine heartwood compared with sapwood has been widely reported (Purslow, 1976; Evans et al., 1988; Gray, 1990) and is attributed to the presence of fungitoxic phenolic extractives (Erdtman and Rennerfelt, 1944; Rennerfelt, 1945). Inhibition of spore germination of the brown rot organism *G. trabeum* and the soft rot organism *Chaetomium globosum* was recorded on both Scots pine heartwood and on water agar impregnated with organic solvent

soluble extracts from Scots pine heartwood (Gray, 1990). The presence of extractives in Scots pine heartwood may therefore account for the reduced decay susceptibility of this species compared with Norway spruce.

Scots pine sapwood has also been reported to inhibit spore germination of a variety of basidiomycetes. In particular, Hegarty and Buchwald (1988) recorded germination inhibition of a number of decay fungi, including *G.trabeum* and *T.versicolor*, the test fungi used in this study. Bjurman (1986) also reported germination inhibition of a variety of basidiomycetes, including *T.versicolor*, on water soluble extracts of Scots pine sapwood. The author later confirmed the presence of phenolic compounds which were assumed to be responsible for the inhibitory activity (Bjurman, 1988). The presence of inhibitors to basidiospore germination in Scots pine sapwood may therefore enhance protection against decay in the treated sapwood portions of this species during prolonged exposure periods.

Fungitoxic substances have also been reported in the heartwood of Norway spruce and were found to have higher water solubility than those present in pine species (Shain and Hillis, 1971). It was suggested by Evans et al (1988) that this increased solubility may limit their ability to confer permanent natural durability in soil contact. Indeed, Evans et al (1988) found no significant increase in decay resistance of Norway spruce heartwood compared with sapwood after soil burial, or exposure to a variety of basidiomycetes in pure culture (Evans et al., 1986a, unpublished report). Brown rot decay of the untreated heartwood of CCA-treated Norway spruce pole sections by *G.trabeum* in this

present study confirms the lack of natural heartwood decay resistance of this species.

The untreated heartwood core of CCA-treated Sitka spruce sections was found to be highly susceptible to decay by the brown rot organism, *G. trabeum*. Decay was initiated at the border between CCA treated sapwood and untreated heartwood, and extended towards the pith with prolonged burial periods. After 18 months burial the heartwood of several sections was totally degraded by brown rot decay (Figure 3.20). Extensive decay of this wood species is associated with the very narrow band of CCA penetration and low uptake levels of the preservative (Figure 3.33), resulting in the exposure of a large surface area of non-durable heartwood to the decay fungi. In some cases, decay pockets occurred at internal positions which were entirely separate from the site of inoculation i.e. checked surface (Figure 3.21 (b) and (c), Figure 3.22 (a)). Isolations from these decayed regions confirmed the presence of *G. trabeum*, a component of the initial inoculum, and it would appear that the fungus has grown away from the checked surface to proliferate at a more suitable location within the timber. While this may simply indicate that the physical conditions at these sites are more suitable for decay, lack of decay development at the checked surface may be a consequence of antagonism by soil organisms against the basidiomycete at this location.

Antagonistic responses of mould fungi against basidiomycetes have been previously reported by a variety of authors, as reviewed by Bruce (1992) and Freitag et al (1991), and artificial inoculation by *Trichoderma* and *Scytalidium* spp. has been examined

as a possible means of controlling internal decay within creosoted distribution poles (Bruce, 1983; Bruce and King, 1986). In this present study, antagonistic interactions were evident when some of the mould fungi isolated from pole sections buried within the accelerated decay system were tested against the basidiomycetes. Cross-reactivity studies confirmed that isolates of *Trichoderma* spp. *Fusarium* spp. and *Gliocladium* spp. caused lysis of both *G. trabeum* and *T.versicolor* under the test conditions used (Table 3.15). Although these lytic effects were recorded in agar interaction studies, this does not guarantee that they will occur in wood itself. Baker and Cook (1974) suggested a number of reasons for this lack of reproducibility of laboratory results under field conditions, including the very low nutrient status of wood in comparison to agar which may limit the production of active metabolites. Srinivasan et al (1992) has also shown that the modes of action of *Trichoderma* spp. against wood decay basidiomycetes is significantly influenced by the composition of the substrate in which the test is undertaken.

It is possible that antagonism by soil organisms at the checked surface may also account for the lack of colonisation by *T. versicolor,* however, mould isolates from the pole sections showed similar responses to both the white and brown rot test fungi during cross-reactivity testing (Table 3.15), and therefore the other factors highlighted earlier may be more important in explaining selective colonisation by *G. trabeum*.

Although basidiomycete decay was recorded in CCA-treated pole sections, the mycelial inoculum failed to induce colonisation and produce decay of untreated control sections.

Decay of control sections was caused entirely by soft rot organisms, except for one basidiomycete sprayed Sitka spruce section which was totally decayed by brown rot (Figure 3.15). Due to the extensive decayed state of this section, isolations were unsuccessful and therefore the presence of *G. trabeum* could not be confirmed, despite attempts to analyse the decayed wood by SDS-PAGE.

Establishment of brown rot decay in this one section may have resulted from poor physical conditions within the wood e.g. low moisture content or low nutrient availability, which may have limited colonisation by soil organisms and therefore allowed the heavy *G. trabeum* inoculum to colonise the wood. Poor soil packing into the check of this particular section may have also been a contributing factor, by reducing the antagonistic actions of the natural soil microflora, and therefore allowing rapid colonisation by the basidiomycete.

3.4.5. Patterns of Decay.

Colonisation and succession of fungal organisms in untreated and CCA-treated softwoods have been studied by several authors (Butcher, 1968, 1972; Greaves, 1972; Greaves and Savory, 1965; Kaarik, 1967, 1968). Butcher (1968) found that the succession of infections in below ground regions of untreated and CCA-treated material were similar, progressing from moulds to soft rot to basidiomycete decay. Infection by soft rot organisms in both CCA-treated and untreated wood was found to be limited to the surface layers and rapidly succeeded by basidiomycete infection

(Butcher, 1968, 1972).

Exposure of pole sections of the four softwood species in the accelerated decay system during this study, resulted in some very interesting patterns of decay. In the soft rot decay system, where untreated and CCA-treated sections were exposed to the natural soil microflora, decay of the pole sections was caused entirely by soft rot organisms. Untreated control sections showed progressive soft rot extending inwards from the curved and checked surface, while CCA-treated pole sections showed only small, isolated pockets of soft rot in untreated portions of their checked surfaces. No decay of the treated curved surface was noted after 24 months soil burial.

Pole sections inoculated with the basidiomycete mycelial spray showed a very different pattern of fungal attack, with heavy brown rot decay developing in the untreated internal regions of CCA-treated spruce sections, particularly Sitka spruce. In untreated control sections however, inoculation with the basidiomycete organisms showed no effect on colonisation and decay patterns of the wood. As in the soft rot test system, decay was caused primarily by soft rot organisms along the curved and checked surfaces. Only one isolated incidence of basidiomycete attack occurred, causing total degradation of an untreated Sitka spruce section by brown rot decay.

It is important to highlight the differences between microbial succession studies of workers such as Butcher (1968, 1972) and Greaves (1972), and the type of study involved in this present project. The early studies on small stakes relied heavily on the isolation and identification of fungal colonisers in

separate test samples of untreated and treated material (Butcher, 1968, 1972; Greaves, 1972; Greaves and Savory, 1965). In the case of treated material, small stakes were employed which were fully treated to very low CCA retentions (Butcher, 1972), and therefore showed little resemblance to commercial products used in ground contact, such as poles.

In this present study however, instead of studying the microbial ecology of treated and untreated wood separately, the performance of a finished wood product was examined i.e. CCA-treated softwood poles. Unlike the fungal succession studies mentioned above, patterns of decay development were examined by microscopic and macroscopic examination of the wood, to determine the locations of different types of decay within a partially treated and checked wooden pole product.

In order to encompass the overall decay hazard that poles are exposed to in the field situation, wood specimens in this study were designed to represent as many of the physical properties of poles as possible. Consequently, quarter pole sections were cut from full size poles CCA-treated by the commercial sap-displacement process and possessed the characteristic untreated heartwood core surrounded by a treated sapwood band. Checks extending into the untreated heartwood were also included to represent the natural checking which commonly occurs in the field. Patterns of decay development during accelerated testing of these wood sections, showed the importance of determining the spatial separation of decay by each of the different fungal types at separate locations within the sections. This study therefore takes a different approach to examining the

decay of treated material under accelerated decay conditions to that taken in earlier studies.

Untreated control sections were attacked by soft rot organisms even when artificially inoculated by basidiomycetes, particularly on the curved tangential wood surface. The severity of soft rot attack was found to be dependent on wood species, with the pines affected more than the spruces. Decay extended radially inwards with increasing exposure time, and also developed on the internal checked face. Indeed, in the case of Corsican pine, decay from the tangential and checked surfaces converged after only 12 months soil burial, resulting in complete decay of the pole sections by soft rot organisms.

Unlike the studies of Kaarik (1967, 1968) where heavy basidiomycete decay of small untreated pine and spruce poles occurred after 18 months field exposure, during this study, no brown or white rot decay was observed in untreated sections after 24 months soil exposure. While continued soil exposure may have resulted in a succession of basidiomycetes in the soft rotted pole sections, the lack of basidiomycete decay may also be due to the different temperature and humidity conditions of the accelerated decay system compared with the field situation. Clubbe (1983) also reported the effect of soil moisture content on decay of treated and untreated birch stakes in a soil-bed, finding that soft rot developed in wetter soils while basidiomycete decay occurred under drier conditions. Since moisture content of the soil was maintained at 100% W.H.C. and untreated control sections generally showed high surface moisture levels, this may account for the high incidence of soft rot in

the sections.

Butcher (1968) also commented that the course and speed of succession in untreated pine was influenced by both the source of infection and the moisture content of the wood. The basidiomycete decay of a single Sitka spruce section inoculated with the mycelial spray, may have therefore resulted from low moisture conditions within this individual section, since this wood species generally showed the lowest moisture uptake of the four test species (Figures 3.11-3.14). Poor soil packing within the check may also have limited competition of the spray inoculum by the natural soil microflora, thereby allowing colonisation and decay by the basidiomycete.

In contrast to the results from untreated material, CCA-treated pole sections showed very different patterns of decay. In the soft rot test system (i.e. those sections not inoculated by basidiomycetes), only small pockets of internal soft rot were observed in untreated material or at positions where CCA retention was very low as a result of the gradient in CCA concentration within the pole sections (Figures 3.30-3.33). No decay of the outer curved tangential surface was recorded after 24 months soil exposure, even in Sitka spruce where significantly lower levels of CCA were recorded. Butcher (1972) suggested that the presence of CCA was the major influence on fungal succession in treated material, resulting in much slower colonisation of the material compared with untreated wood. Pine stakes used by Butcher (1972), were however, treated to a very low CCA retention, unlike the highly treated outer regions of the pole sections used in this present study. Although total

protection against this type of decay may be conferred by high preservative levels on the outer surfaces, continued soil exposure may result in decay development in the inner treated regions of the checked surfaces where CCA retentions are much lower.

Artificial inoculation of pole sections with the brown and white rot organisms resulted in totally different decay patterns. In untreated sections, decay development was unaffected by the inoculum presence and the natural soil microflora proceeded to colonise the timber and cause soft rot decay. The presence of CCA, and its effect on reducing moisture uptake did however, result in extensive brown rot decay of the treated spruce sections. Successful colonisation by the basidiomycete inoculum in these treated species may be attributed to the much lower moisture contents recorded in these wood sections compared with untreated control sections (Figures 3.11-3.14). Although moisture contents were still above fibre saturation point and therefore not limiting to fungal attack, the lower moisture levels may have encouraged basidiomycete attack in preference to soft rot fungi within the soil, as previously reported by Clubbe (1983).

Leaching of CCA components from the pole sections to soil packed within their checks may have resulted in the inhibition of the natural soil microflora. This inhibitory effect of metals in soil was previously shown by a significant decrease in soil dehydrogenase activity adjacent to CCA-treated sections (Tables 3.2 & 3.3). This leaching effect may therefore explain successful establishment of the basidiomycete inoculum, due to reduced

competition by the natural soil microflora.

A number of mould fungi were isolated from both the treated and untreated pole sections. Most of these fungi have been isolated during previous studies (Butcher, 1968, 1972; Greaves, 1972; Greaves and Savory, 1965: Kaarik, 1967, 1968) and were generally reported to be non-decay producing deuteromycetes. While these fungal species may not be responsible for decay of the pole sections, they may, in time, be involved in the detoxification of the preservative thereby rendering the CCA less effective in protecting the wood from less-tolerant decay fungi. Detoxification of a variety of preservatives has previously been reported for some of the moulds isolated in this study i.e. *Fusarium* spp. (Madhosingh, 1961), *Graphium* spp. (Duncan and Deverall, 1964) and *Trichoderma* spp. (Unligil, 1968). Detoxification of CCA during long term exposure of treated poles may play an important role in the colonisation and decay by organisms after the toxic limits of the CCA are reduced.

Surveys on the occurrence and types of decay affecting CCA-treated softwood posts or poles during long-term field exposure have reported soft rot to be the most common decay type (Schmidt and Jacobsson, 1976; Friis-Hansen and Lundstrom, 1977; Nilsson, 1984; Drysdale et al., 1986; Friis-Hansen, 1989). Exposure of sap-displacement treated pole sections within the accelerated decay system have shown a lack of soft rot development in the outer treated surfaces, but have highlighted the possible problems associated with basidiomycete decay of internal regions. The presence of checks, particularly in poorly treated species such as Sitka spruce, provide an ideal avenue of entry for

basidiomycete spores, and it was shown that establishment of this type of decay could lead to extensive internal decay of pole sections. If this is indeed the case, failure of CCA-treated poles by internal decay may occur in a similar manner to internal decay of creosote-treated poles by *L. lepideus* (Cartwright and Findlay, 1958). Although soft rot development of internal surfaces, as reported in this study, is not expected to cause as serious a decay hazard as basidiomycete fungi, it remains an important consideration in the use of heavily checked, poorly treated wood species, such as Sitka spruce.

CHAPTER 4

GENERAL DISCUSSION

4. GENERAL DISCUSSION.

4.1. Suitability of UK Grown Softwood Poles CCA-treated by Sap-displacement.

One of the principle aims of this research project was to examine the relative performances of poles of the four softwood species after CCA-treatment by pressurised sap-displacement. This was undertaken by examination of full size poles in a field site, and representative pole sections in an accelerated decay system, and showed definite species effects in the treatability and decay susceptibility of the four wood species.

In terms of the current British Standard for treatment of poles with CCA (B.S. 4072, 1987), it is specified that full sapwood penetration by the preservative should be achieved. The four test species satisfy this criterion when treated with CCA by the high pressure sap-displacement process, however, results from performance testing of the treated material in this study show major differences in the treatment and decay susceptibility of the four species, and indicate that one species, namely Sitka spruce, is not suitable for use in its present form.

Of the four wood species, Corsican pine was found to be the most readily treated, with penetration of the preservative extending to full sapwood depth, leaving a very small proportion of untreated heartwood at the core of the poles. CCA retention in this species was also shown to be excellent, with very high levels of copper, chromium and arsenic recorded to radial depths of at least 80mm. These high levels of preservative retention and

penetration conferred almost total protection against microbial decay during accelerated testing of pole sections. Only a few very small pockets of surface soft rot occurred in the untreated heartwood core as a result of fungal colonisation from soil which had become compacted into the open check. Protection against decay was provided despite the high susceptibility of this wood species to soft rot decay in its untreated form, as shown by the extensive decay of untreated control sections in the accelerated decay system. The high decay susceptibility of this species, resulting from its high nutrient status, has also been shown to cause colonisation and decay of poles during drying periods prior to conventional pressure impregnation processes (Morrell et al., 1987; Zahora and Dickinson, 1989). Treatment of Corsican pine poles by sap-displacement therefore provides an ideal product, while at the same time eliminating the pre-treatment drying period during which decay may occur.

Although the results of this study indicate that Corsican pine poles CCA-treated by sap-displacement could be recommended for commercial use, it is possible that the treatment time could be reduced whilst still conferring adequate protection against microbial decay. Reduction in treatment time from the standard 40 hour cycle, and any resultant reduction in preservative uptake, may reduce overall supply costs of the treated product whilst still retaining the decay resistance seen in this study, and thereby increasing the attractiveness of this wood species to pole users.

In contrast to Corsican pine, CCA-treated Scots pine poles showed lower levels of preservative retention and penetration. Treatment of this wood species was however, shown to provide good protection against both soft rot and basidiomycete decay. The presence of CCA inhibited soft rot decay of the outer curved surfaces, but compaction of soil into the untreated heartwood region resulted in small areas of soft rot development beyond the treated sapwood zone. Inoculation with the basidiomycete spray also caused a surface decay effect in the untreated regions which appeared to be brown rot, but despite many attempts, basidiomycete decay fungi were not isolated from these regions. Since adequate levels of CCA penetration and retention were achieved, and protection against internal and external decay conferred, Scots pine poles treated with CCA by pressurised sap-displacement can be expected to perform well over longer service periods.

Although a detailed investigation of the comparative service performances of Scots pine poles CCA-treated by sap-displacement and creosote-treated by conventional pressure impregnation processes has not been undertaken, on the basis of results from this study i.e. high levels of CCA treatment and permanence, and lack of decay development, it could reasonably be expected that the CCA-treated product will perform equally as well as the creosoted product. Problems encountered with variable penetration levels of creosote which are often associated with inadequate drying of poles prior to treatment (Morris and Calver, 1985), are not expected during the sap-displacement process with CCA, since pre-treatment drying is not required, and full sapwood

penetration is therefore more likely to occur. The occurrence of internal basidiomycete decay which is often reported in creosote treated poles (Cartwright and Findlay, 1958), and is thought to initiate in a narrow band of untreated, non-durable sapwood, will therefore be eliminated.

Performance of the CCA-treated spruces, particularly Sitka spruce, was found to be much poorer than the pines. Although Norway spruce possessed similar levels of CCA penetration and retention to Scots pine, it was found to be more susceptible to internal soft rot and basidiomycete decay during exposure to accelerated decay conditions. As explained previously this may be due to the natural decay resistance of Scots pine heartwood caused by the presence of fungitoxic phenolic extractives (Erdtman and Rennerfelt, 1944; Rennerfelt, 1945). Internal decay of treated Norway spruce pole sections in the accelerated decay system was attributed to the presence of checks which extended into the non-durable heartwood region. In the field situation, Norway spruce poles showed more extensive checking than the pines, however, these checks did not generally extend past the band of CCA-treatment (Table 2.9; Evans et al., 1991). These results suggest that high pressure sap-displacement with CCA is suitable for the treatment and long term protection of poles of this species under service conditions, however, reduction in the extent of checking by methods such as kerfing (Ruddick, 1988; Morrell, 1990) or the addition of polyethylene glycol to the treatment system (Trumble and Messina, 1986) would be advisable to ensure extended protection against internal decay.

CCA-treatment of Sitka spruce by sap-displacement produced significantly lower depths of preservative penetration (Table 2.4) and levels of retention (Table 2.5) than the other three test species. Although the CCA-treated outer sapwood was not affected by soft rot after two years burial in the accelerated decay system, extensive internal brown rot decay of the large untreated region did occur after inoculation with the basidiomycete mycelia. As in the case of Norway spruce, this decay was associated with the presence of opened checks extending into the untreated, non-durable heartwood. Full size poles of this species in the field showed severe checking which often exceeded the mean depth of CCA penetration (Table 2.9; Evans et al., 1991), thus increasing the likelihood of internal decay development of the untreated core. Isolation of basidiomycete decay fungi from internal regions of Sitka spruce poles after only four years field exposure provides evidence that early colonisation of the untreated inner regions of heavily checked poles does occur.

Although CCA-treatment of Sitka spruce poles was poor in comparison to the other three test species, penetration to full sapwood depth is the only requirement in the current British Standard (B.S. 4072, 1987), therefore poles of this species would generally satisfy the standard. The early fungal colonisation of field exposed, CCA-treated Sitka spruce poles in this study, does however, emphasise the need for more strict treatment regulations, as in the Technical Specification of the Electricity Association (Electricity Association, Technical Specification 43-88, 1987) where a minimum preservative pentration of 35mm, and

minimum total dry salt retention of 10kg/m^3 is required for Norway and Sitka spruce poles.

On the evidence of results from this study, CCA-treatment by sap-displacement appears to be unsuitable for long term field performance of Sitka spruce poles, due to the reasons discussed above. Sitka spruce is however, the most commonly planted softwood species in the UK (Harding, 1988), therefore there is an obvious incentive to tackle these problems in order to obtain a commercially viable product. Reduction in the extent of checking by the methods mentioned previously i.e.kerfing and CCA-PEG, and increasing permeability of the wood to preservatives e.g. ponding, excising, ozone-treatment (see section 1.4), are possible solutions to this problem and are currently the subject of other research projects.

Chemical analysis of preservative levels within the field exposed poles has shown that, to date, losses and re-distribution of the CCA components have not caused an environmental hazard, nor are they likely to adversely affect field performance of the poles. It would however, be useful to continue monitoring the field exposed poles to determine if leaching of the preservative salts is continuing, and whether CCA contents fall below those levels required to protect the timber. Continued monitoring of the decay status of all the field poles would also reinforce the findings from the accelerated decay system, particularly in view of the isolation of decay fungi from Sitka spruce poles after only four years exposure.

4.2. Development of the Accelerated Decay System.

Development of the accelerated decay system not only allowed direct comparison of decay susceptibility of the four wood species, but proved to be a useful vehicle for examining the patterns of decay development in large dimension timbers. As mentioned previously, the wood specimens were unique in their design and were carefully modelled to represent, as closely as possible, the field exposed poles. They were cut from poles commercially treated by high pressure sap-displacement to give loadings and distribution of the preservative similar to those in the field, and consisted of quarter pole sections to incorporate both the treated and untreated regions which are characteristic of field poles. As in the field situation, only the outer curved surface was in direct contact with the soil, with a styrene resin coating the remaining radial longitudinal surfaces and the base of the sections. A natural check within each section was opened to the depth of untreated heartwood to represent possible natural checking in the field situation. All these factors were found to play important roles in the subsequent patterns of decay development and highlighted the importance of using truly representative samples for accelerated testing of poles.

A variety of techniques were introduced to examine the location of different decay types within the CCA-treated and untreated control sections. In the examination of soft rot development of external surfaces, dehydrogenase, pilodyn and microscopic analyses showed excellent correlation, confirming extensive soft rot decay of the curved surfaces of untreated

control sections and prevention of soft rot decay in the CCA-treated sections. An initial increase in soil dehydrogenase activity adjacent to treated sections was accompanied by the isolation of a wide variety of mould organisms from the wood at the 6 month sampling period, however continued exposure of these sections resulted in slight inhibition of microbial activity, in the soil as a result of CCA components leaching from the wood to soil. This protective effect of CCA-treatment was indeed confirmed by pilodyn and microscopic analysis of the adjacent wood surfaces where no soft rot decay was detected.

The presence of checks in the test sections proved to be an important aspect of sample design. While decay of the treated outer surfaces was inhibited, internal soft rot and basidiomycete decay was observed along the checked faces of treated sections, particularly Sitka spruce sections. Basidiomycete decay occurred only in those treated sections sprayed with the artificial inoculum of *G. trabeum* and *T. versicolor*. The production and use of this type of artificial inoculum was developed for this project, and was introduced to the sections to represent natural infection of poles by basidiomycete spores via open checks. Viability of the macerated mycelial extract was initially confirmed on agar and was later shown to be successful in the colonisation and decay of wood sections. Decay was caused solely by the brown rot organism, demonstrating the host preferences of brown rot and white rot decay fungi. Reasons for this preferential decay of softwoods by brown rot fungi, and hardwoods by white rot fungi, are described in section 2.4.3.

Spatial differences in the location and type of decay found in the untreated and CCA-treated pole sections of the four test species confirmed the importance of using wood samples which more closely represented the commercial product when examining their decay susceptibility under accelerated conditions. The interesting patterns of decay development found in CCA-treated pole sections therefore show the limitations of using small stakes in decay testing of treated timber products, particularly poles. The use of small, fully treated wood stakes do not represent the variable composition of wood poles, where both treated and untreated material are present, and where checks facilitate the entry of decay fungi to untreated inner regions. Though stake tests are useful in the initial screening of new treated products, the overall design of the accelerated decay system and test specimens used in this present study, give a clearer indication of the types of decay hazard which may occur in the field.

4.3. Appraisal of the Accelerated Decay System for Testing the Decay Susceptibility of poles CCA-treated by Sap-Displacement.

Within the time scale of this study, little information on the decay susceptibility of the four wood species could be made based solely on the results from the field test. Although decay fungi were isolated from two of the Sitka spruce poles, no visual signs of decay were evident in any of the wood species. The accelerated decay system was therefore found to be very useful in

providing information on the comparative decay susceptibility of the four test species during the three years of this project. Though considerable acceleration of the decay processes was achieved within the accelerated decay system, it is important to note that many environmental differences existed between the field and laboratory systems which may affect progression of the decay processes.

A major difference between the field and accelerated test systems, was the lack of precipitation in the latter. Lack of precipitation in the laboratory system was found to affect both the moisture status of the pole sections, and the re-distribution and leaching of preservative components which were identified in the field situation. Lower moisture contents were recorded in pole sections compared with the field poles and were almost certainly affected by the lack of precipitation in the accelerated decay system. These low moisture levels may also have been a consequence of the initial soaking procedure of pole sections which was required to raise the initial moisture levels prior to soil burial. Green et al (1989) reported that leaching of small, CCA-treated woodblocks caused reduced moisture uptake during subsequent soil burial periods. It is therefore possible that wetting of the sections prior to soil burial may have had a similar effect. Although moisture contents of treated sections were above fibre saturation point, and therefore not decay limiting, moisture differences between field poles and pole sections would invariably affect rates and patterns of colonisation.

Another consequence of precipitation which was not represented in the laboratory system, and which may have affected fungal colonisation, was the seasonal opening and closing of checks due to fluctuations in moisture levels within the poles. Checks within pole sections were kept open throughout the operation of the accelerated decay system, thereby increasing the decay hazard to internal untreated regions. Though this may not truly represent the field situation, it facilitated the study of the influence of checking on fungal colonisation and internal decay.

While leaching of CCA components occurred from pole sections to the adjacent soil, the extent to which this occurred was much smaller than in the field. In addition, re-distribution of copper, chromium and arsenic, which was recorded in the field poles, was not reproduced during soil exposure in the accelerated decay system. Both these factors were due to the lack of precipitation in the laboratory system, therefore it is important to realise that although accelerated testing systems are very useful in examining what may occur in the field, exposure of the treated commercial product under service conditions is required for accurate monitoring of the movement and permanence of wood preservatives. It is possible, however, to include simulated rainfall in the design of accelerated laboratory systems, as suggested by Hedley (1980), which would therefore enable a closer representation of the field situation.

High temperature, humidity and soil moisture conditions were incorporated into the design of the accelerated decay system to provide optimum conditions for fungal attack, however, varying

these factors may have affected the natural colonisation process. The ecology of decay under such accelerated conditions may therefore not be truly representative of that found under field conditions. This factor was discussed by Ruddick (1989) who questioned the similarity of biological succession observed under these two test conditions. Although this present study did not examine microbial succession patterns, the isolation of white rot fungi from Sitka spruce field poles compared with preferential colonisation and decay by brown rot fungi in the accelerated decay system may well highlight environmental differences between the two test systems.

Previous workers have confirmed that this type of laboratory-based test system does accelerate decay compared with the field situation. Hedley (1983) reported that treated samples incubated in a fungal cellar decayed 7-12 times faster than similarly treated samples exposed in the field. Similarly, Polman et al (1991) found a 2-4 times acceleration of decay of untreated stakes in a soil-bed system compared with identical stakes in the field. Problems do however, arise in extrapolating results from accelerated testing of wood specimens to determine the field performance of full size commercial products, such as poles. While this type of facility is a very effective means of providing information on the longer term performance of the timbers, it is not feasible to extrapolate the results in an attempt to predict the absolute service life of poles, since environmental differences between the field and laboratory systems are likely to affect the decay processes. The larger, more representative samples used in this study have however,

proven to be more useful in examining the possible field performance of full size products.

Development of the accelerated decay system was found to be invaluable for comparison of decay susceptibility of the treated species. The system provided considerable acceleration of the decay processes, as indicated by the extent of decay compared to field material, and has enabled valuable comparisons to be made between the four species within the three years duration of the study. While this type of system does not simulate all conditions present in the field situation, from the results of this study it can be concluded that the accelerated decay system can be a very reliable addition to long term field testing for the decay assessment of treated distribution poles. As reported by Ruddick (1989), fungal cellars can form an important stage in the development and testing of untreated and treated material provided that their limitations in predicting service life are realised.

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APPENDICES

APPENDIX I.

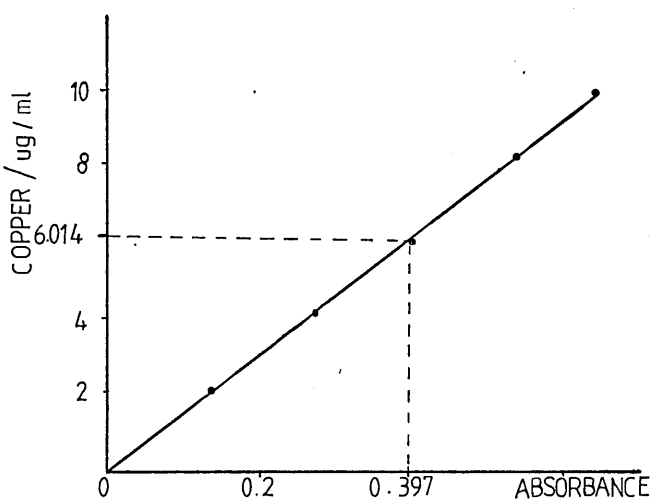
Conversion of test sample absorbance readings to metal concentration by the standard curve method

Example:-

Test sample copper absorbance measurement = 0.397
Original dry weight of wood sample = 0.0488g

Copper Standard Curve :	ug/ml Cu	Absorbance
	0	0.000
	2	0.143
	4	0.274
	6	0.402
	8	0.531
	10	0.641

Correlation Co-efficient = 0.9993
(using computer programme)



From curve;

Test sample absorbance of 0.397 = 6.014 ug/ml copper

Therefore, total copper in 25ml sample = 1.504×10^{-4} g

and, % weight/weight (metal/wood) = $\frac{1.504 \times 10^{-4}}{0.0488} \times 100$ %

= 0.308% copper

APPENDIX II.

Conversion of test sample absorbance readings to metal concentration by the standard additions method.

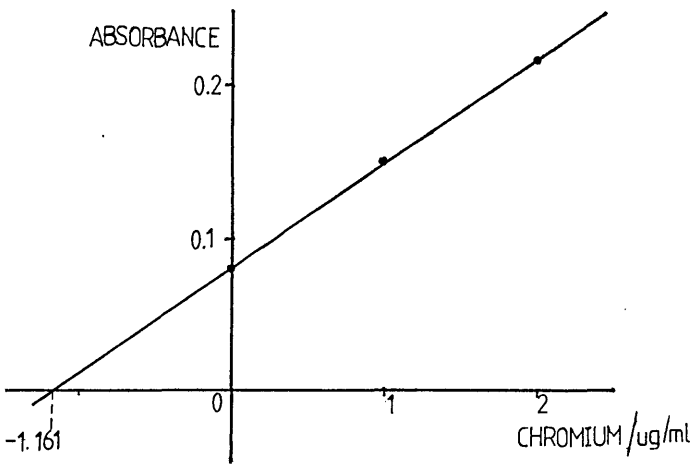
Example:-

Original dry weight of soil = 3.4566g

Chromium measurements :

Flask	Added Cr (ug/ml)	Absorbance
A	0	0.079
B	1	0.149
C	2	0.216

Correlation Co-efficient = 1.000
(using computer programme)



From curve:

x-intercept = -1.161

Thus, 1.161 ug chromium is present per ml

and, total chromium in original 100ml sample = 145.12 ug

Therefore, there is $\frac{145.12}{3.4566}$ ug Cr / g soil

= 41.98ug chromium per gram soil.

APPENDIX III. Copper, Chromium and Arsenic Contents of Radial Samples Removed from Poles after 0, 1, 2 and 3 Years Field Exposure.

Table 1. Mean metal concentrations of copper, chromium and arsenic in Corsican pine poles after 0, 1, 2 and 3 years field exposure.

Year	Sample Height	Depth of Sample(mm)	Metal Concentration (% w/w) Copper	Chromium	Arsenic
0	GL	0-10	0.39±0.038	1.08±0.129	0.68±0.057
		10-30	0.43±0.047	0.78±0.082	0.62±0.028
		30-50	0.58±0.069	0.62±0.076	0.51±0.108
		50-70	0.52±0.071	0.50±0.057	0.36±0.054
		70-100	0.21±0.181	0.23±0.182	0.15±0.117
1	GL	0-10	0.48±0.050	1.38±0.177	1.26±0.314
		20-30	0.44±0.099	0.83±0.156	1.08±0.204
		40-50	0.52±0.103	0.71±0.114	0.96±0.278
		60-70	0.51±0.093	0.58±0.128	0.80±0.382
		80-90	0.41±0.158	0.46±0.148	0.54±0.344
	1m	0-10	0.40±0.045	1.19±0.235	1.22±0.496
		20-30	0.50±0.105	0.79±0.110	1.04±0.287
		40-50	0.56±0.085	0.65±0.119	0.89±0.366
		60-70	0.50±0.172	0.56±0.176	0.81±0.431
		80-90	0.26±0.225	0.35±0.310	0.48±0.517
2	GL	0-10	0.45±0.068	0.99±0.445	1.08±0.156
		20-30	0.47±0.089	0.88±0.174	1.04±0.222
		40-50	0.52±0.100	0.73±0.142	0.93±0.259
		60-70	0.56±0.111	0.63±0.150	0.76±0.351
		80-90	0.48±0.204	0.52±0.188	0.63±0.369
	1m	0-10	0.46±0.082	0.98±0.307	1.02±0.278
		20-30	0.53±0.046	0.78±0.157	0.94±0.190
		40-50	0.56±0.093	0.72±0.144	0.84±0.259
		60-70	0.52±0.255	0.63±0.171	0.72±0.598
		80-90	0.44±0.299	0.52±0.375	0.60±0.445
3	GL	0-10	0.51±0.094	1.41±0.181	1.12±0.151
		20-30	0.40±0.096	0.90±0.118	0.94±0.140
		40-50	0.55±0.089	0.74±0.116	0.86±0.123
		60-70	0.54±0.117	0.59±0.124	0.66±0.237
		80-90	0.47±0.122	0.54±0.099	0.48±0.163
	1m	0-10	0.44±0.048	1.17±0.228	1.04±0.129
		20-30	0.52±0.085	0.79±0.126	0.90±0.138
		40-50	0.58±0.108	0.66±0.140	0.73±0.281
		60-70	0.48±0.165	0.55±0.187	0.53±0.269
		80-90	0.25±0.247	0.29±0.268	0.31±0.295

GL - groundline
1m - height of 1m above ground.
Year 0 data from Evans et al (1987a)

Table 2. Mean metal concentrations of copper, chromium and arsenic in Scots pine poles after 0, 1, 2 and 3 years field exposure.

Year	Sample Height	Depth of Sample(mm)	Metal Concentration (% w/w) Copper	Chromium	Arsenic
0	GL	0-10	0.40±0.091	0.84±0.140	0.65±0.159
		10-20	0.38±0.083	0.59±0.083	0.66±0.118
		20-40	0.52±0.074	0.51±0.052	0.62±0.134
		40-100	0.22±0.156	0.24±0.184	0.34±0.152
1	GL	0-10	0.70±0.204	1.46±0.379	1.15±0.322
		10-20	0.64±0.123	0.89±0.226	1.22±0.300
		20-30	0.65±0.132	0.79±0.168	1.06±0.246
		30-40	0.60±0.184	0.66±0.193	0.78±0.370
		40-50	0.50±0.267	0.50±0.238	0.63±0.399
		50-60	0.39±0.202	0.40±0.141	0.36±0.210
	1m	0-10	0.59±0.117	1.20±0.212	1.13±0.258
		10-20	0.67±0.134	0.83±0.167	1.16±0.317
		20-30	0.63±0.205	0.79±0.343	0.90±0.370
		30-40	0.68±0.216	0.66±0.182	0.80±0.328
		40-50	0.46±0.220	0.46±0.220	0.55±0.197
		50-60	0.12±0.126	0.12±0.130	0.08±0.075
2	GL	0-5	0.65±0.137	1.45±0.535	1.17±0.352
		5-15	0.41±0.081	0.84±0.240	1.08±0.275
		15-25	0.49±0.128	0.82±0.161	1.12±0.110
		25-35	0.54±0.081	0.74±0.133	1.05±0.175
		35-45	0.62±0.089	0.68±0.088	1.07±0.306
		45-55	0.56±0.064	0.56±0.091	0.81±0.191
		55-65	0.46±0.133	0.47±0.105	0.61±0.244
	1m	0-5	0.52±0.138	1.13±0.359	1.07±0.282
		5-15	0.46±0.078	0.83±0.166	1.04±0.078
		15-25	0.54±0.083	0.75±0.117	1.06±0.170
		25-35	0.56±0.086	0.66±0.159	1.04±0.302
		35-45	0.52±0.195	0.55±0.208	0.86±0.376
		45-55	0.46±0.189	0.45±0.158	0.59±0.267
		55-65	0.28±0.313	0.29±0.249	0.35±0.353
3	GL	0-5	0.65±0.130	1.59±0.400	1.01±0.214
		5-15	0.40±0.080	0.84±0.215	0.90±0.232
		15-25	0.46±0.120	0.74±0.146	0.90±0.254
		25-35	0.52±0.102	0.74±0.143	0.77±0.307
		35-45	0.50±0.103	0.66±0.161	0.71±0.328
		45-55	0.51±0.193	0.58±0.227	0.72±0.273
		55-65	0.50±0.100	0.52±0.104	0.62±0.190
	1m	0-5	0.50±0.132	1.22±0.378	0.76±0.297
		5-15	0.44±0.088	0.73±0.158	0.78±0.183
		15-25	0.50±0.072	0.70±0.146	0.82±0.167
		25-35	0.54±0.101	0.63±0.154	0.76±0.258
		35-45	0.51±0.189	0.54±0.199	0.62±0.232
		45-55	0.41±0.191	0.41±0.196	0.41±0.229
		55-65	0.17±0.167	0.20±0.192	0.16±0.160

Year 0 data from Evans et al (1987a).

Table 3. Mean metal concentrations of copper, chromium and arsenic in Norway spruce poles after 0, 1, 2 and 3 years field exposure.

Year	Sample Height	Depth of Sample(mm)	Metal Concentration (% w/w) Copper	Chromium	Arsenic
0	GL	0-10	0.40±0.048	0.83±0.335	0.64±0.188
		10-20	0.42±0.152	0.52±0.189	0.60±0.189
		20-100	0.18±0.137	0.17±0.124	0.17±0.125
1	GL	0-5	0.58±0.128	1.45±0.417	0.99±0.304
		5-15	0.47±0.059	0.76±0.192	1.00±0.097
		15-25	0.52±0.066	0.68±0.135	0.94±0.190
		25-35	0.52±0.115	0.59±0.131	0.76±0.304
		35-45	0.44±0.063	0.50±0.070	0.59±0.170
		45-55	0.31±0.141	0.33±0.108	0.28±0.108
		55-65	0.10±0.099	0.22±0.134	0.09±0.085
	1m	0-5	0.49±0.097	1.22±0.306	0.99±0.113
		5-15	0.46±0.058	0.72±0.163	0.90±0.259
		15-25	0.50±0.118	0.57±0.134	0.74±0.216
		25-35	0.39±0.149	0.44±0.129	0.49±0.204
		35-45	0.21±0.149	0.30±0.145	0.24±0.189
		45-55	0.05±0.084	0.14±0.084	0.09±0.090
		55-65	0.00±0.000	0.00±0.000	0.00±0.000
2	GL	0-5	0.63±0.163	1.77±0.636	1.18±0.508
		5-15	0.45±0.097	0.75±0.278	0.94±0.399
		15-25	0.47±0.141	0.61±0.140	0.74±0.296
		25-35	0.42±0.195	0.52±0.206	0.57±0.323
		35-45	0.30±0.194	0.39±0.276	0.38±0.354
		45-55	0.17±0.192	0.22±0.234	0.21±0.282
		55-65	0.06±0.152	0.09±0.206	0.08±0.217
	1m	0-5	0.54±0.088	1.36±0.432	0.93±0.276
		5-15	0.50±0.051	0.77±0.162	0.92±0.238
		15-25	0.54±0.057	0.69±0.168	0.79±0.192
		25-35	0.46±0.147	0.53±0.156	0.55±0.216
		35-45	0.24±0.159	0.31±0.186	0.26±0.223
		45-55	0.05±0.091	0.09±0.137	0.05±0.099
		55-65	0.00±0.000	0.00±0.000	0.00±0.003
3	GL	0-5	0.68±0.142	1.52±0.295	0.75±0.236
		5-15	0.42±0.108	0.72±0.262	0.67±0.283
		15-25	0.46±0.117	0.74±0.238	0.72±0.257
		25-35	0.52±0.093	0.70±0.209	0.71±0.215
		35-45	0.59±0.080	0.68±0.144	0.73±0.185
		45-55	0.47±0.172	0.54±0.110	0.50±0.238
		55-65	0.29±0.174	0.38±0.227	0.33±0.271
	1m	0-5	0.53±0.088	1.38±0.326	0.71±0.168
		5-15	0.47±0.062	0.72±0.135	0.71±0.119
		15-25	0.51±0.106	0.62±0.137	0.64±0.231
		25-35	0.39±0.162	0.44±0.175	0.38±0.197
		35-45	0.20±0.157	0.28±0.176	0.18±0.169
		45-55	0.02±0.037	0.04±0.068	0.01±0.026
		55-65	0.00+0.000	0.00+0.000	0.00+0.001

Year 0 data from Evans et al (1987a).

Table 4. Mean metal concentrations of copper, chromium and arsenic in Sitka spruce poles after 0, 1, 2 and 3 years field exposure.

Year	Sample Height	Depth of Sample(mm)	Metal Concentration (% w/w) Copper	Chromium	Arsenic
0	GL	0-10	0.15±0.068	0.29±0.110	0.20±0.086
		10-20	0.06±0.056	0.07±0.049	0.08±0.054
		20-100	0.00±0.027	0.00±0.002	0.00±0.001
1	GL	0-10	0.32±0.141	0.82±0.475	0.47±0.300
		10-20	0.18±0.102	0.22±0.109	0.23±0.118
		20-30	0.09±0.128	0.12±0.152	0.10±0.113
		30-40	0.01±0.009	0.01±0.012	0.01±0.013
	1m	0-10	0.35±0.145	0.65±0.277	0.56±0.234
		10-20	0.14±0.149	0.18±0.167	0.21±0.181
		20-30	0.07±0.061	0.12±0.107	0.09±0.016
		30-40	0.00±0.002	0.00±0.003	0.00±0.002
2	GL	0-10	0.26±0.083	0.55±0.171	0.39±0.162
		10-20	0.15±0.094	0.22±0.136	0.21±0.136
		20-30	0.06±0.072	0.08±0.090	0.07±0.060
		30-40	0.01±0.011	0.01±0.016	0.01±0.014
	1m	0-10	0.24±0.092	0.49±0.175	0.40±0.210
		10-20	0.15±0.111	0.17±0.109	0.19±0.120
		20-30	0.04±0.066	0.06±0.082	0.04±0.055
		30-40	0.01±0.014	0.01±0.029	0.01±0.017
3	GL	0-10	0.28±0.103	0.59±0.180	0.36±0.140
		10-20	0.20±0.122	0.24±0.136	0.23±0.140
		20-30	0.10±0.093	0.14±0.111	0.10±0.076
		30-40	0.03±0.054	0.05±0.082	0.03±0.042
	1m	0-10	0.25±0.094	0.54±0.190	0.33±0.138
		10-20	0.10±0.102	0.13±0.107	0.12±0.096
		20-30	0.04±0.063	0.05±0.076	0.03±0.064
		30-40	0.00±0.004	0.00±0.005	0.00±0.005

Year 0 data from Evans et al (1987a).

APPENDIX IV. Copper, Chromium and Arsenic Contents of Radial Samples Removed from Poles of the Four Wood Species at the Groundline, 3.5m and 6.5m.

Table 1. Mean metal concentrations of copper, chromium and arsenic measured at the groundline, and at heights of 3.5m and 6.5m in Corsican pine poles after 4 years field exposure.

Sampling Height	Depth of Sample(mm)	Metal Concentration (% w/w) Copper	Chromium	Arsenic
GL	0-10	0.52±0.085	1.27±0.273	1.03±0.128
	20-30	0.35±0.073	0.88±0.134	0.99±0.162
	40-50	0.57±0.069	0.80±0.047	1.06±0.079
	60-70	0.60±0.090	0.63±0.089	0.80±0.209
	80-90	0.54±0.106	0.55±0.052	0.53±0.144
3.5m	0-10	0.42±0.054	1.12±0.220	0.93±0.104
	20-30	0.57±0.118	0.78±0.090	0.91±0.880
	40-50	0.61±0.027	0.67±0.728	0.68±0.130
	60-70	0.59±0.085	0.66±0.143	0.70±0.200
	80-90	0.34±0.227	0.45±0.327	0.42±0.311
6.5m	0-10	0.52±0.071	1.08±0.305	1.02±0.123
	20-30	0.65±0.096	0.75±0.156	0.88±0.190
	40-50	0.60±0.203	0.63±0.246	0.72±0.319
	60-70	0.62±0.289	0.64±0.311	0.70±0.358

GL - groundline.
3.5m/6.5m - height above groundline.

Table 2. Mean metal concentrations of copper, chromium and arsenic measured at the groundline, and at heights of 3.5m and 6.5m in Scots pine poles after 4 years field exposure.

Sampling Height	Depth of Sample(mm)	Metal Concentration (% w/w) Copper	Chromium	Arsenic
GL	0-5	0.74±0.159	1.82±0.353	1.14±0.210
	5-15	0.38±0.086	1.00±0.069	1.07±0.171
	15-25	0.41±0.090	0.91±0.131	1.03±0.160
	25-35	0.52±0.095	0.77±0.018	1.03±0.051
	35-45	0.57±0.094	0.72±0.087	1.00±0.134
	45-55	0.56±0.100	0.67±0.129	0.88±0.231
	55-65	0.57±0.048	0.60±0.079	0.76±0.183
3.5m	0-5	0.42±0.054	1.25±0.187	1.13±0.220
	5-15	0.43±0.081	0.86±0.051	1.07±0.114
	15-25	0.57±0.036	0.71±0.069	0.99±0.074
	25-35	0.58±0.060	0.59±0.072	0.77±0.205
	35-45	0.40±0.258	0.41±0.239	0.50±0.360
	45-55	0.17±0.202	0.24±0.213	0.20±0.244
	55-65	0.02±0.023	0.05±0.058	0.03±0.023
6.5m	0-5	0.44±0.049	1.17±0.390	1.23±0.226
	5-15	0.50±0.094	0.79±0.154	1.04±0.248
	15-25	0.60±0.054	0.64±0.113	1.04±0.300
	25-35	0.60±0.040	0.60±0.033	0.83±0.154
	35-45	0.43±0.281	0.42±0.266	0.57±0.391
	45-55	0.24±0.278	0.24±0.259	0.32±0.375
	55-65	0.11±0.257	0.11±0.249	0.14±0.341

Table 3. Mean metal concentrations of copper, chromium and arsenic measured at the groundline, and at heights of 3.5m and 6.5m in Norway spruce poles after 4 years field exposure.

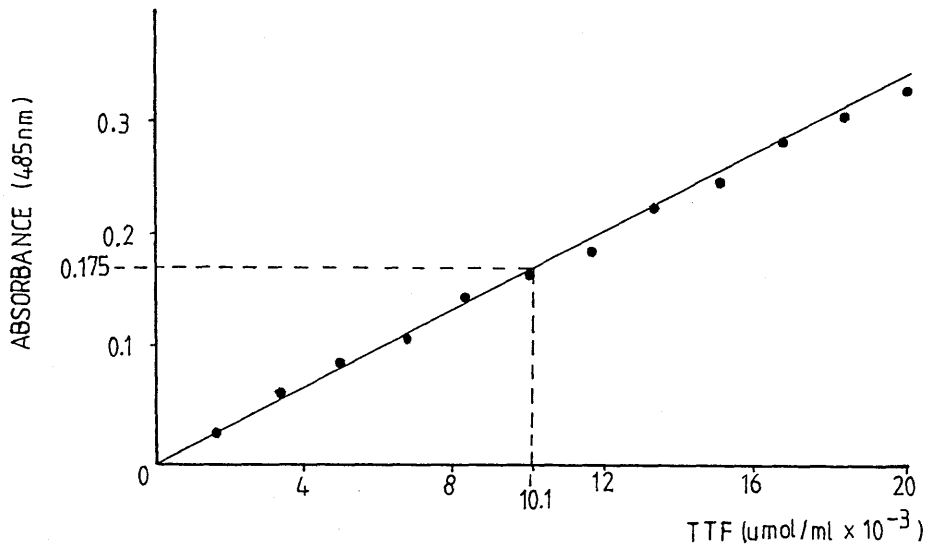
Sampling Height	Depth of Sample(mm)	Metal Concentration (% w/w) Copper	Chromium	Arsenic
GL	0-5	0.70±0.197	1.82±0.719	1.11±0.171
	5-15	0.43±0.045	0.84±0.187	0.91±0.209
	15-25	0.53±0.068	0.74±0.112	0.86±0.104
	25-35	0.56±0.070	0.72±0.200	0.82±0.119
	35-45	0.53±0.080	0.65±0.174	0.73±0.241
	45-55	0.39±0.156	0.47±0.175	0.42±0.301
	55-65	0.23±0.158	0.36±0.215	0.27±0.334
3.5m	0-5	0.52±0.072	1.27±0.418	0.98±0.394
	5-15	0.51±0.094	0.68±0.143	0.78±0.175
	15-25	0.53±0.130	0.59±0.190	0.66±0.310
	25-35	0.48±0.206	0.50±0.264	0.54±0.407
	35-45	0.32±0.196	0.32±0.200	0.26±0.247
	45-55	0.09±0.140	0.11±0.139	0.09±0.119
	55-65	0.00±0.001	0.00±0.000	0.00±0.000
6.5m	0-5	0.52±0.040	1.06±0.275	0.62±0.182
	5-15	0.48±0.111	0.67±0.204	0.68±0.258
	15-25	0.55±0.118	0.64±0.148	0.62±0.256
	25-35	0.38±0.116	0.42±0.116	0.35±0.131
	35-45	0.02±0.035	0.05±0.056	0.02±0.029
	45-55	0.00±0.013	0.01±0.017	0.01±0.008
	55-65	0.00±0.000	0.00±0.000	0.00±0.000

Table 4. Mean metal concentrations of copper, chromium and arsenic measured at the groundline, and at heights of 3.5m and 6.5m in Sitka spruce poles after 4 years field exposure.

Sampling Height	Depth of Sample(mm)	Metal Concentration (% w/w) Copper	Chromium	Arsenic
GL	0-10	0.16±0.028	0.41±0.068	0.24±0.050
	10-20	0.13±0.061	0.14±0.054	0.16±0.079
	20-30	0.06±0.079	0.08±0.091	0.07±0.092
	30-40	0.02±0.031	0.03±0.037	0.03±0.034
3.5m	0-10	0.15±0.056	0.21±0.168	0.19±0.087
	10-20	0.04±0.060	0.05±0.055	0.06±0.085
	20-30	0.00±0.000	0.00±0.008	0.00±0.010
	30-40	0.00±0.000	0.00±0.000	0.00±0.000
6.5m	0-10	0.15±0.033	0.25±0.085	0.22±0.037
	10-20	0.03±0.036	0.03±0.036	0.04±0.052
	20-30	0.00±0.000	0.00±0.002	0.00±0.000
	30-40	0.00±0.000	0.00±0.002	0.00±0.000

APPENDIX V.

Determination of Soil Dehydrogense Activity Measurements.



Absorbance of test soil sample = 0.175

Therefore, from curve = 10.1×10^{-3} umol/ml

Wet weight of soil = 1.5290 g

Moisture content of soil = 20.8%

Therefore, dry weight of soil = 1.2657 g

$$\text{Dehydrogenase Activity} = \frac{10 \times (10.1 \times 10^{-3})}{1.2657 \times 1440}$$

$$= 5.57 \times 10^{-5} \text{ umol TTF/g/min}$$

(note: 10 = total volume of sample
1440 = incubation time in minutes)

APPENDIX VI.

Solution recipes for SDS-PAGE and silver staining methods.

Boiling Mix :- 125mM Tris-HCl (pH 6.8)
2mM dithiothreit
2% sodium dodecyl sulphate
20% glycerol
5% mercaptoethanol
bromophenol blue

Silver Stain Solutions.

Pre-treatment :-	sodium thiosulphate	0.5 mg
	ultra-pure water	250 ml
Impregnate :-	silver nitrate	0.5 g
	37% formaldehyde	187.5 ul
	ultra-pure water	250 ml
Develop :-	sodium carbonate (anhydrous)	15 g
	37% formaldehyde	125 ul
	sodium thiosulphate	1.0 mg
	ultra-pure water	250 ml
Stop solution :-	methanol	500 ml
	glacial acetic acid	120 ml
	ultra-pure water	380 ml

PUBLICATIONS

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S.D.Hainey, G.M.Smith, A.Bruce, P.D.Evans, B.King and H.J.Staines (1989).
Field evaluation of CCA movement in sap-displaced copper chrome arsenic treated softwood poles.
Internat. Res. Group on Wood Preserv. Doc. No. IRG/WP/3539.

P.D.Evans, S.D.Hainey, A.Bruce, G.M.Smith and B.King (1990).
The suitability of high pressure sap-displacement for the treatment of UK grown spruce and pine.
Internat. Res. Group on Wood Preserv. Doc. No. IRG/WP/3595.

A.Bruce, S.D.Hainey, G.M.Smith, B.King and P.D.Evans (1990).
Studies in an accelerated soil bed facility on the decay susceptibility of UK grown spruce and pine poles treated with copper/chrome/arsenic (CCA) by pressurised sap-displacement 1. Setting up of soil beds and initial soft rot results.
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Holz als Roh-und Werkstoff. 49, pp 1-6.

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Working Group III Preservatives and Methods of Treatment

Field evaluation of CCA movement in sap-displaced copper chrome arsenic treated softwood poles.

by

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FIELD EVALUATION OF CCA MOVEMENT IN SAP-DISPLACED COPPER CHROME ARSENIC TREATED SOFTWOOD POLES

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Abstract

Commercial sap-displaced UK grown Scots and Corsican pine, and Sitka and Norway spruce poles were exposed in a field site at Dundee, Scotland and radial distribution profiles of CCA monitored prior to implantation and after subsequent field exposure. Results show that groundline levels of all preservative elements were higher after 1 and 2 years field exposure compared with those recorded prior to pole implantation. In addition, chemical analyses of the soils at the groundline regions of the poles showed that raised metal levels were detectable. Some of the implications of the results are discussed.

Keywords: sap-displacement, copper chrome arsenic (CCA), Corsican pine, Scots pine, Norway spruce, Sitka spruce, wood poles

Introduction

At present, the Electricity Supply Industry in the UK imports the majority of its poles for use as overhead line supports. It has been reported however, that UK grown softwood poles of sufficient size and strength are available for this use (Fowlie,1981). The large quantities of such poles, particularly spruce species, and the economic advantages of their utilisation by the industry, has resulted in several investigations into their suitability being undertaken (Fowlie,1981, Fowlie and Sheard,1983, Evans et al.,1987).

Spruce spp., especially Sitka spruce, are naturally refractive timbers which are difficult to treat with preservatives by conventional impregnation processes (Smith and Cockcroft,1961). An alternative to the traditional pressure treatment of such species is the use of pressurised sap-displacement. In this process the sap of freshly felled timber is replaced by preservative, usually water-borne formulations such as copper chrome arsenic (CCA). An advantage of this process is that it eliminates the need for the extended drying periods that are required prior to traditional pressure impregnation processes. This is an important consideration since various authors have recently reported the significance of pre-treatment infection of wood poles during prolonged drying periods (Morrell et al.,1987, Przyblylowicz et al.,1987). In addition, sap-displacement has also been reported to give a deeper, more even impregnation of the preservative than is obtained with conventional pressure processes (Gersonde,1968).

Although there have been numerous reports on the permanence of CCA in small wood blocks and stakes examined under laboratory conditions (Rak and Clarke,1974, DeGroot et al.,1979, Norton,1979), there have been very few reports on the monitoring of CCA permanence in full size poles treated by

commercial impregnation processes. In particular, little information seems to be available on the permanence of CCA in poles CCA-treated by the commercial sap-displacement process.

Earlier studies at this laboratory examined preservative levels in Corsican pine, Scots pine, Norway spruce and Sitka spruce poles treated with CCA by commercial sap-displacement prior to their insertion into a field site near Dundee (Evans et al.,1986, 1987). This paper describes the results of CCA element analysis of cores removed from the groundline regions of these poles after 1 and 2 years field exposure. In addition, results of soil analysis from around the bases of the poles are reported.

Methods

Wood sampling and analysis

Five UK grown 10m poles of each of Corsican pine (*Pinus nigra* var *maritima* Ait), Scots pine (*Pinus sylvestris*. L.), Norway spruce (*Picea abies*. L. Karst) and Sitka spruce (*Picea sitchensis* (Bong) Carr) were commercially treated by pressurised sap-displacement using a 1.8% CCA type C solution. After treatment, two poles of each species were randomly selected and sampled to establish the levels of copper, chromium and arsenic prior to field implantation (Evans et al.,1986, 1987).

Three months after treatment, the 20 poles were erected in a modified Latin square pattern at a field site near Dundee, Scotland and re-sampled after 1 and 2 years field exposure. At each of the sampling times two core samples (4mm diameter) were removed from opposite sides of the groundline region of each pole (i.e. a total of 10 cores for each species). The cores were sectioned according to the plan in Fig.1. Each individual core section was finely divided using a scalpel and the copper, chromium and arsenic extracted from the wood according to B.S.5666:part 3 (1979). The resulting solutions were then analysed for copper, chromium and arsenic content by atomic absorption spectrophotometry (Williams,1972).

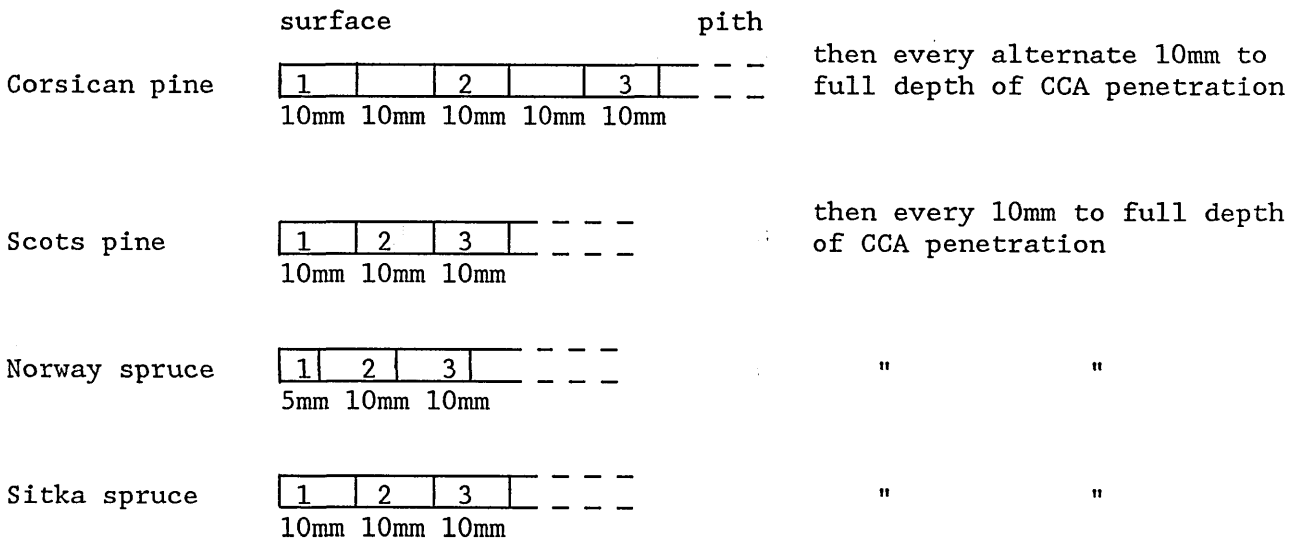


Figure 1. Pattern of sectioning of wood cores.

Soil sampling and analysis

Thirty months after pole implantation, soil samples taken just below the groundline level at each pole were removed and analysed for preservative element content.

Two samples (10mm wide) were taken from immediately adjacent to the wood surface at opposite sides of each pole at a depth of 100mm below the soil surface. Twelve samples were also removed as background controls from within the pole layout site at locations 2.5m from any one pole. After air drying, the samples were sieved to pass a 2mm stainless steel sieve, ground in a mortar and pestle and dried at $102\pm2^{\circ}C$ for at least 3 hours. The copper, chromium and arsenic content of the soils were then extracted using sulphuric acid (2.5M) and hydrogen peroxide (100 vol). The preservative element content of the resultant solutions were then determined by atomic absorption spectrophotometry using a standard additions technique. The extraction method employed was as described by Green (1988) but its use was checked for suitability with this particular soil (classified as a slightly clayey, sandy loam) by determining the percentage recoveries of copper, chromium and arsenic from control samples artificially loaded with a standard CCA solution. Average recoveries of 97%, 91% and 100% were achieved for copper, chromium and arsenic, respectively.

Results

Groundline CCA levels in poles

The radial concentrations of copper, chromium and arsenic in the poles before implantation and after 1 and 2 years field exposure are presented in Figs. 2-5. Each plotted point for year 0 values are means of 12 core samples (6 cores from each of 2 poles), while values for years 1 and 2 are means of 10 core samples (2 cores from each of 5 poles).

The radial concentrations of copper, chromium and arsenic in all four species generally decrease from pole surface to pole centre, however, in Corsican pine, Scots pine and Norway spruce, copper shows an intermediate peak in concentration at varying radial depths of between 15-65mm from the pole surfaces. This type of copper peak is not apparent in Sitka spruce.

Corsican pine, Scots pine and Norway spruce clearly show good preservative penetrations and retentions, but much poorer preservative penetrations and retentions were found in the Sitka spruce poles.

The graphs also indicate that in all of the four wood species tested, groundline levels of the three preservative elements after both the 1 and 2 years sampling periods, were higher than those recorded prior to the poles being erected. Increased levels of the preservative elements were found at both the pole surfaces and throughout the entire radial direction of preservative penetration.

Since the sizes of the core sections used after years 1 and 2 were different from those at year 0, complete statistical analysis of all the radial profiles of preservative elements will require the use of non-standard methods. This data will be presented in a later publication (Hainey,1989). For the purposes of this paper, two way analysis of variance has been carried out on copper, chromium and arsenic levels at a depth of 5mm from the outer surface of each

core to examine the effect of exposure time and wood species on preservative levels. A standard statistical package was used for this purpose (Minitab, Inc. 1987).

Results of the analysis of variance tests of pre and post-implantation levels of copper, chromium and arsenic at the 5mm depth, show that the levels of all preservative elements, irrespective of wood species, are different for years 0, 1 and 2. Further statistical analysis using Scheffé's method of contrast (Scheffé,1953) was used to compare preservative levels at year 0 with those recorded at years 1 and 2. Results for this test are presented in Table 1 and clearly show that copper, chromium and arsenic levels are significantly higher after 1 and 2 years field exposure compared with levels prior to pole implantation. The same method also shows that preservative element levels after year 2 were not significantly different from those recorded at year 1 ($p > 0.05$).

One anomaly was found in these results where chromium levels in Corsican pine poles at year 0 were not significantly different from years 1 and 2 ($p > 0.05$), and those at years 1 and 2 were significantly different ($p < 0.05$). This result is associated with a high standard deviation recorded for the year 2 measurements.

The interaction between wood species and exposure time was not significant.

Table 1. Statistical comparison of copper, chromium and arsenic levels at year 0 with levels after years 1 and 2 (Scheffé's method).

Species	Probability value / p		
	Copper	Chromium	Arsenic
Corsican pine	<0.01	*>0.05*	<0.001
Scots pine	<0.01	<0.001	<0.001
Norway spruce	<0.001	<0.01	<0.01
Sitka spruce	<0.001	<0.01	<0.01

Soil CCA levels

The results of the soil analyses are presented in Table 2. Values for the test samples are an average of 10 replicate samples, whilst those for control samples represent the average of 12 replicates. Comparison of the test sample data with the control data by analysis of variance, shows that the copper and chromium levels in the soils adjacent to the poles are very significantly higher than background levels ($p < 0.001$ for both copper and chromium). Levels of arsenic in soils adjacent to poles were not found to be significantly different from background levels ($p > 0.05$). The only species effect noted which was statistically significant was the elevated chromium levels adjacent to the Sitka spruce poles ($p < 0.05$).

Table 2 Levels of copper, chromium and arsenic in soil sampled adjacent to poles treated with CCA by pressurised sap-displacement.

Species	Copper content µg/g soil	Chromium content µg/g soil	Arsenic content µg/g soil
Corsican pine	145.6 ± 104.78	55.3 ± 12.34	36.4 ± 24.27
Scots pine	180.3 ± 91.46	55.2 ± 10.04	33.0 ± 13.16
Norway spruce	163.0 ± 84.53	55.3 ± 10.70	36.1 ± 15.66
Sitka spruce	203.8 ± 113.18	71.7 ± 17.35	34.4 ± 17.11
Control	37.2 ± 2.94	35.5 ± 1.29	23.7 ± 10.85

Discussion

The analysis data from core samples taken after both 1 and 2 years exposure, showed that some migration of CCA components had occurred. Comparison of the years 1 and 2 data showed no significant difference, implying that such movement had occurred mainly during the first year of exposure. This movement, resulting in increased levels of the preservative salts at the groundline regions, should confer additional protection on that area of the pole which is most susceptible to soft rot decay. A lower level of movement may still be occurring and further sampling will be required to monitor this.

Increased levels of copper and chromium found in the soils adjacent to the poles indicate that some leaching of the preservative elements from the poles has occurred. Although arsenic levels in the wood poles were increased at groundline regions at the 1 and 2 years sampling periods, no significant increase in arsenic levels was recorded in the soil adjacent to the poles. It must be noted however, that soil sampling was carried out only at one sampling period and it is possible that anionic arsenic may have diffused away from the soil adjacent to the pole due to its higher mobility in soil (Jacobs et al.,1970) than that of the other preservative elements, particularly copper (Leeper,1978).

Although Sitka spruce possessed a significantly lower retention and penetration of CCA, it showed a higher proportional loss of chromium than the other three wood species. This effect at low retentions has been previously reported by Arsenault (1975), Dahlgren (1975) and Briscoe (1987) for several different wood species, where the concentration of salts in the wood was found to affect leachability, with higher CCA retentions resulting in reduced leaching of the salt components.

Some redistribution of the preservative elements in CCA treated wood is known to occur on leaching (Drysdale,1984, Green et al.,1989). The rate and degree of fixation of CCA in wood has been found to depend on a number of factors, including pH of the treating solution, time, temperature, concentration of salts within the wood and physical and chemical variability of the wood (Dahlgren and Hartford,1972, Rak and Clarke,1974, Dahlgren ,1975, Pizzi,1982). The poles in this study were treated by a commercial sap-displacement process,

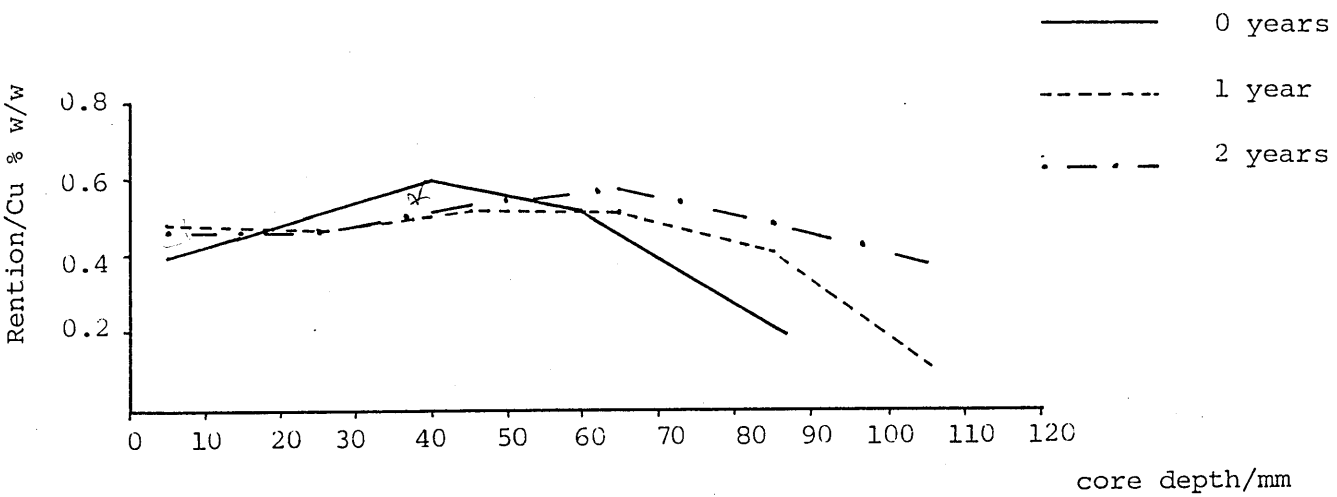
left for a three month period prior to implantation, and samples were removed at one and two year intervals after implantation. DeGroot et al. (1979) determined distribution gradients of copper, chromium and arsenic in soil around stakes CCA-treated by the conventional process and left implanted for 30 years. They concluded that such stakes did not contribute significant amounts of arsenic and chromium into surrounding soils. They found copper levels in the soils to be higher but more variable than the other two preservative elements. The data from this present study points to similar findings for the leaching of the three CCA elements from poles treated by the sap-displacement process.

Visual examination of the poles has shown no presence of surface decay, implying adequate protection is being maintained. Studies will continue to monitor any changes in the levels of preservative elements in these poles and also to detect any colonisation by decay organisms.

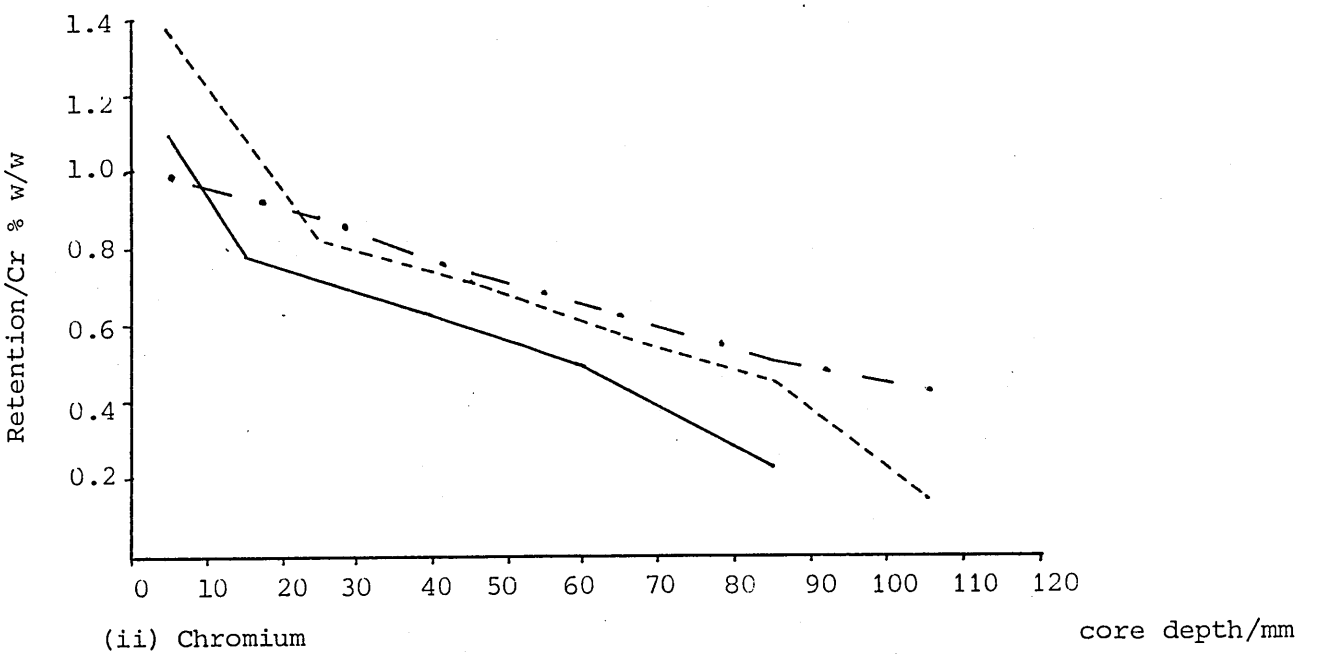
Acknowledgements

The authors wish to thank the Electricity Research Council (UK) for funding in support of this work.

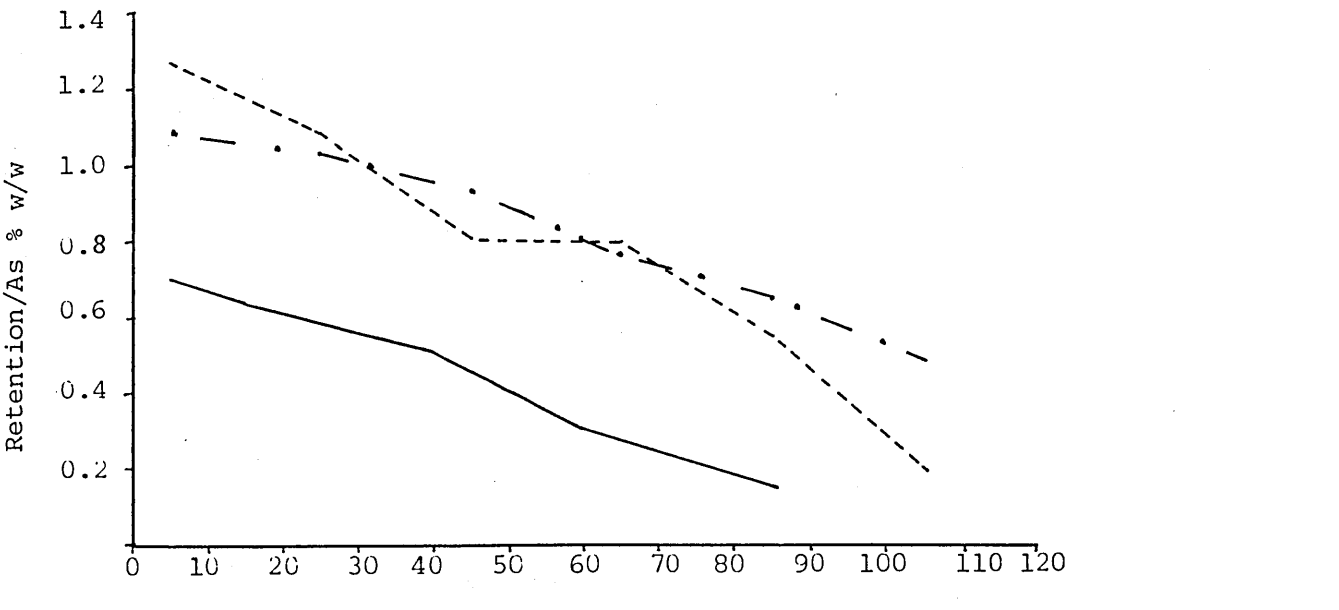
Fig 2 Copper, chromium and arsenic level in Corsican pine poles after 0,1 and 2 years exposure



(i) Copper

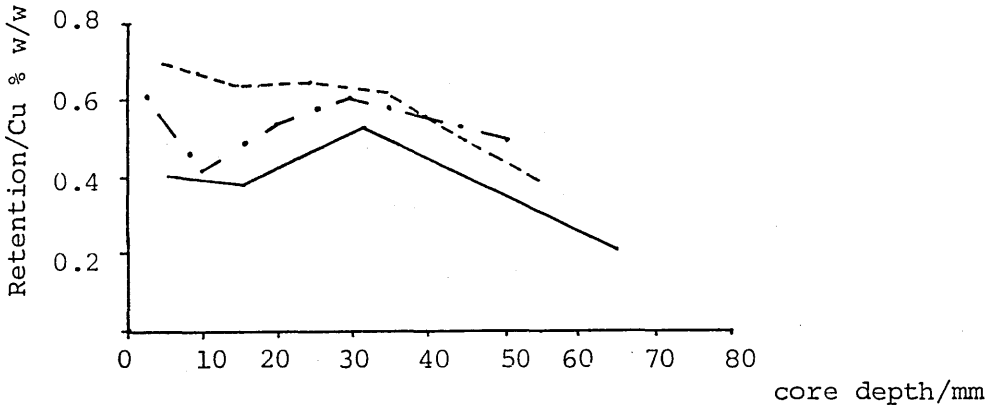


(ii) Chromium

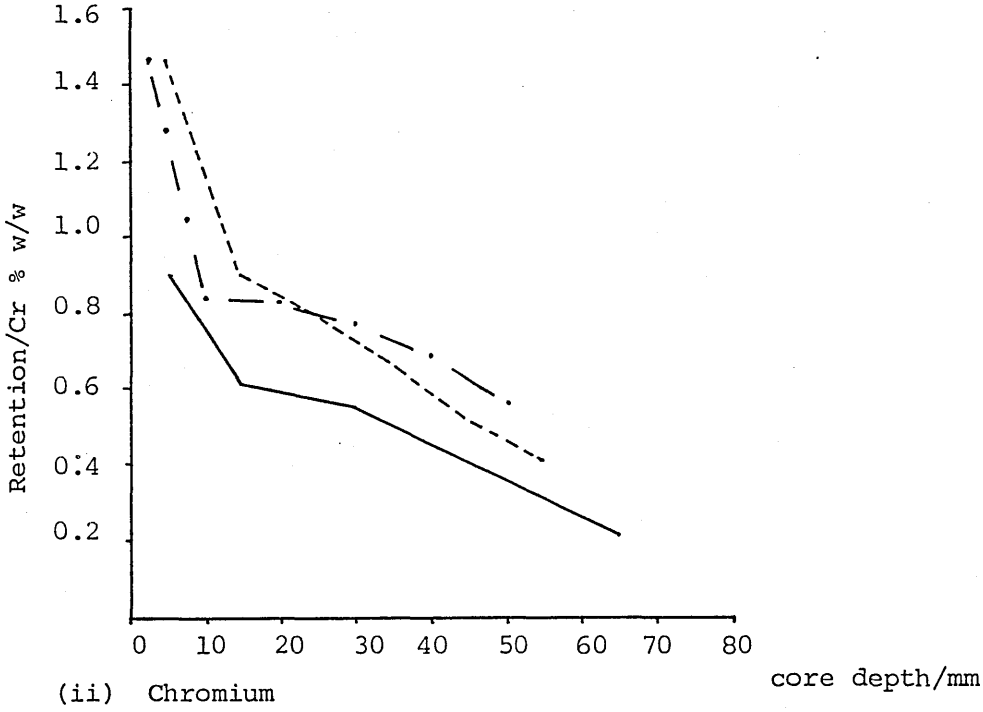


(iii) Arsenic

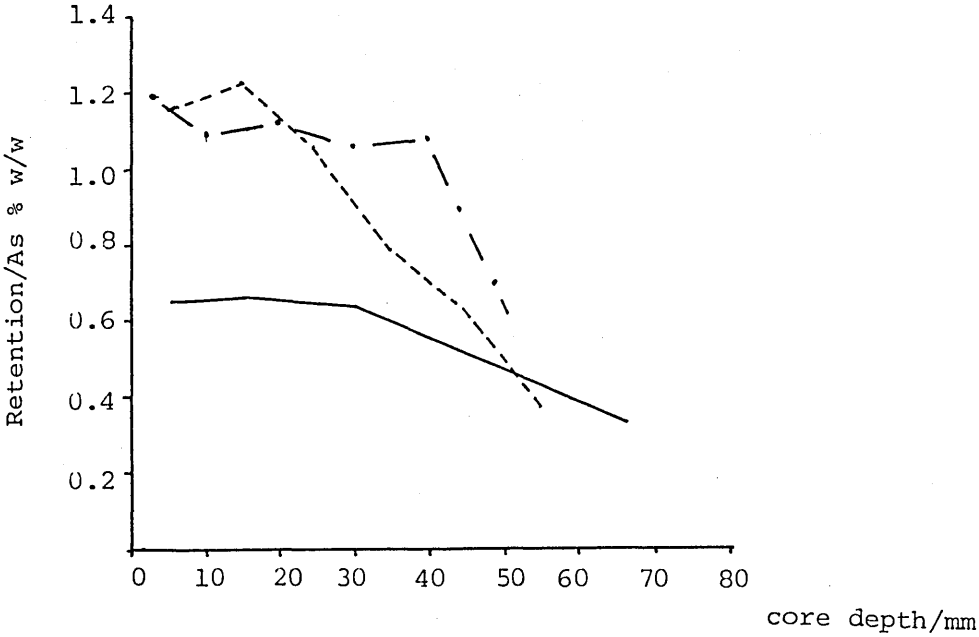
Fig 3 Copper, chromium and arsenic level in Scots pine poles after 0,1 and 2 years exposure



(i) Copper

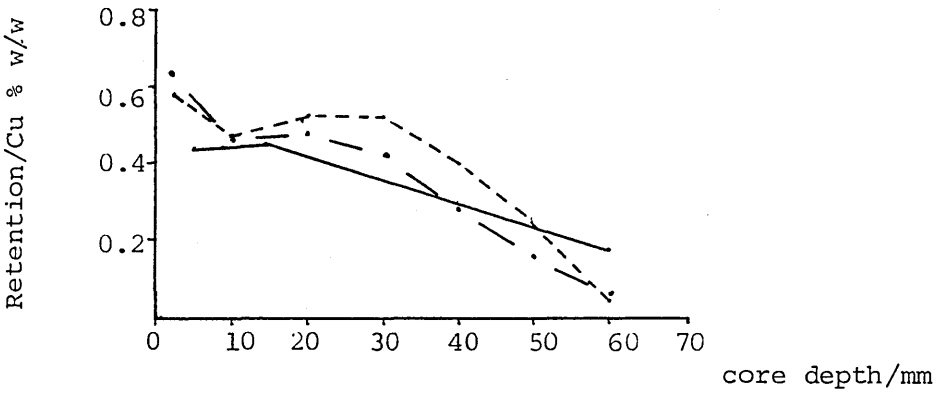


(ii) Chromium

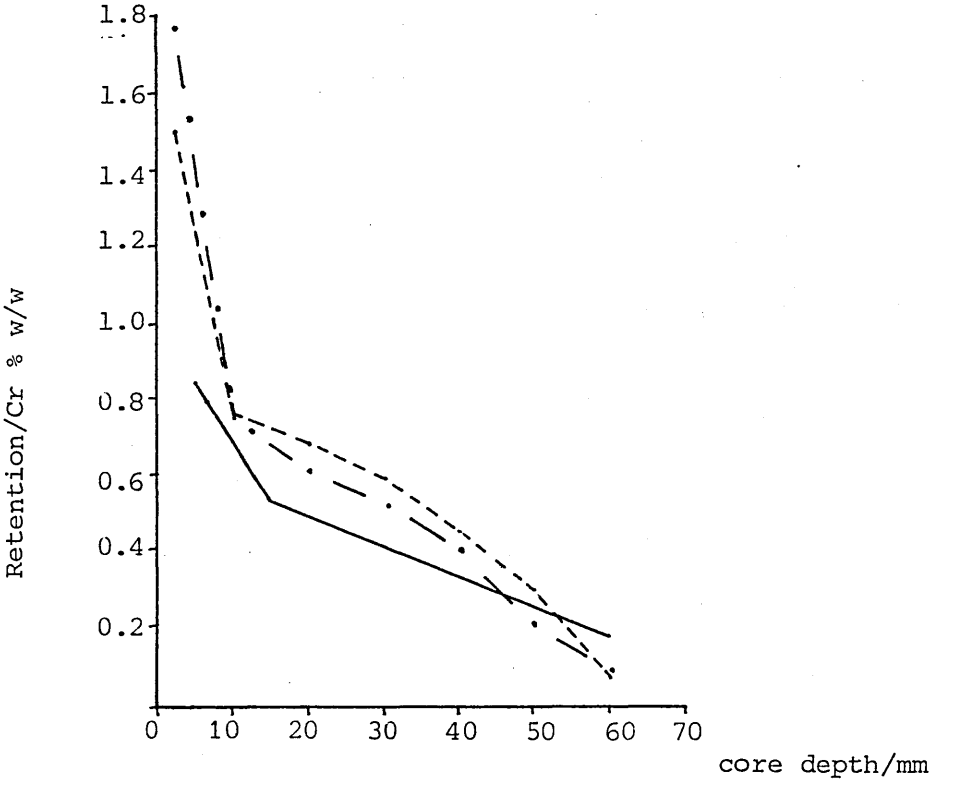


(iii) Arsenic

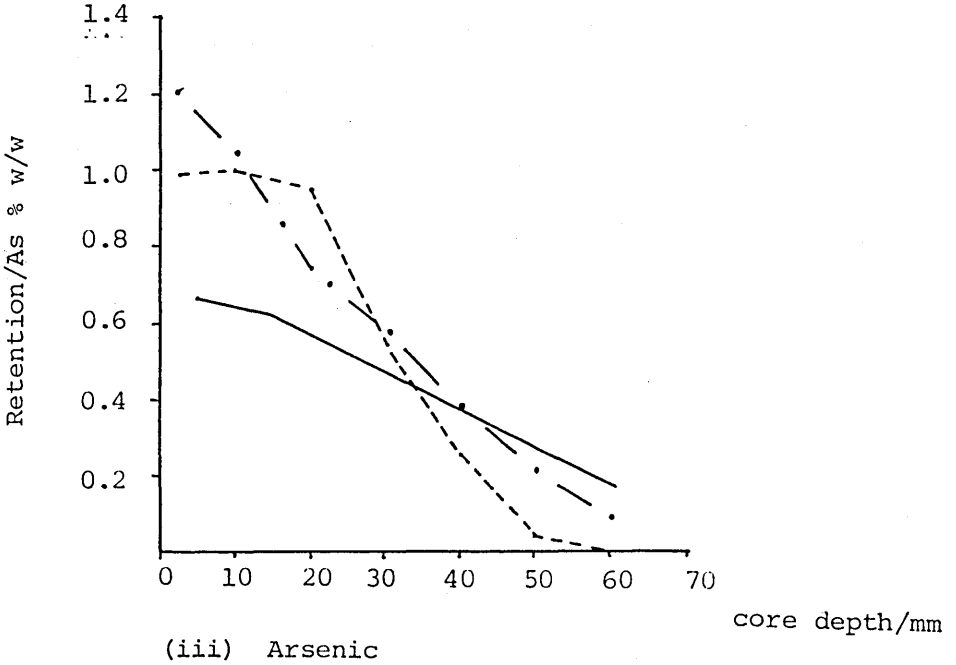
Fig 4 Copper, chromium and arsenic levels in Norway spruce poles after 0,1 and 2 years exposure



(i) Copper

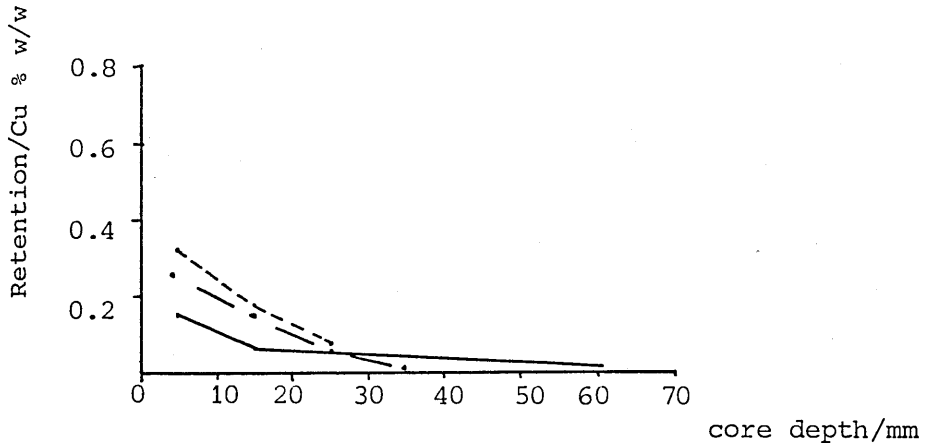


(ii) Chromium

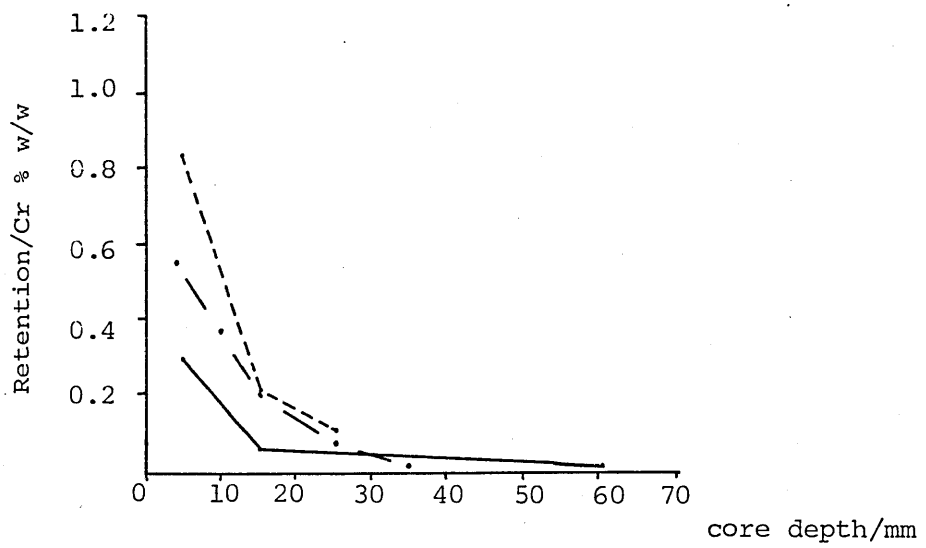


(iii) Arsenic

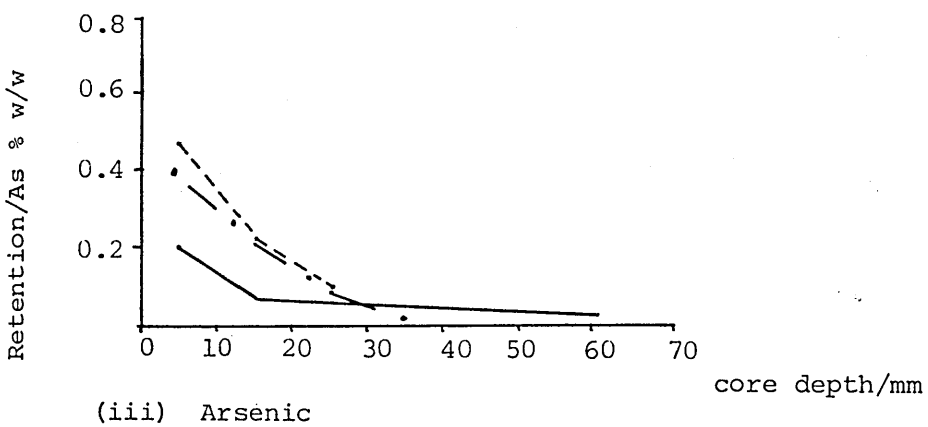
Fig 5 Copper, chromium,arsenic levels in Sitka spruce poles after 0,1 and 2 years exposure



(i) Copper



(ii) Chromium



(iii) Arsenic

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Working Group III Preservatives and Methods of Treatment

Sub-Group 4 Refractory Timbers

The suitability of high pressure sap-displacement for the treatment of U.K. grown spruce and pine

by

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The suitability of high pressure sap-displacement for the treatment of U.K. grown spruce and pine

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Abstract

The concentration and radial distribution of copper, chrome, arsenic (CCA), and the moisture content and depth of radial checking in U.K. grown, field exposed spruce and pine poles treated by high pressure sap-displacement are examined. The concentration of CCA elements in samples obtained from increment cores is similar in Norway spruce, Scots pine and Corsican pine but is significantly lower in Sitka spruce The concentration of chromium in all species, arsenic in Sitka spruce, Norway spruce and Corsican pine and copper in Sitka spruce are at a maximum in the outer sapwood and decrease centripetally with increasing core depth. In contrast, arsenic in Scots pine and Norway spruce at groundline and copper in Norway spruce, Scots pine and Corsican pine are at a maximum in the inner sapwood. The slopes of metal concentration against radial core depth are similar in Norway spruce and Scots pine but are significantly larger (steeper) and smaller (less steep) respectively in Sitka spruce and Corsican pine. Checking is more severe in Sitka spruce than in the other species and appears to be associated with steep moisture gradients. In Sitka spruce, checks penetrate the preservative treated annulus thus greatly facilitating decay since micro-organisms have access to untreated non durable wood.

The results suggest that high pressure sap-displacement is suitable for the treatment and long term protection of Norway spruce, Scots pine, and Corsican pine but is inadequate for the protection of Sitka spruce. Modifications to the high pressure sap-displacement process that could improve the treatment of Sitka spruce are discussed.

Key words: CCA, high pressure sap-displacement, checking, poles, concentration, Sitka spruce, Norway spruce, Scots pine, Corsican pine.

Introduction

The increasing availability and cost attractiveness in the U.K. of rapidly grown Sitka spruce, Norway spruce and Corsican pine have increasingly led to demands for their utilization as poles for overhead line supports. Conventional pressure techniques can be used for the treatment of pine pole species, but they do not produce adequate penetration of preservative in spruce poles (Fowlie 1981). High pressure sap-displacement using copper, chrome, arsenic (CCA) has been suggested as suitable for the treatment of U.K. grown spruce poles (Fowlie and Sheard 1983) since its use results in greater penetration and retention of CCA than may be achieved using conventional pressure preservation processes. An additional advantage of high pressure sap-displacement for the treatment of both spruce and pine poles is that the wood is treated green, thus prolonged drying periods prior to pressure treatment are avoided, reducing the risk of pre-treatment decay. Such decay is common in U.K. pole yards (Zahora and Dickinson 1989) and has been an effective obstacle to the utilization of Corsican pine poles as overhead line supports (Fowlie 1985).

In a preliminary study (Evans et al 1987) the variation in CCA concentration in Sitka and Norway spruce and Scots and Corsican pine poles was examined 4 months after high pressure sap-displacement treatment. Little longitudinal (from butt to top) variation in CCA concentration was found in treated poles and the radial distribution of CCA and its individual metal salts was similar to those reported (McMahon et al 1942; Cokley and Smith unpublished report cited by Norton 1979) for timber treated with CCA by conventional empty and full cell pressure processes. This earlier study (Evans et al 1987) also revealed that the concentration of CCA was lower in Sitka spruce than in the other pole species examined.

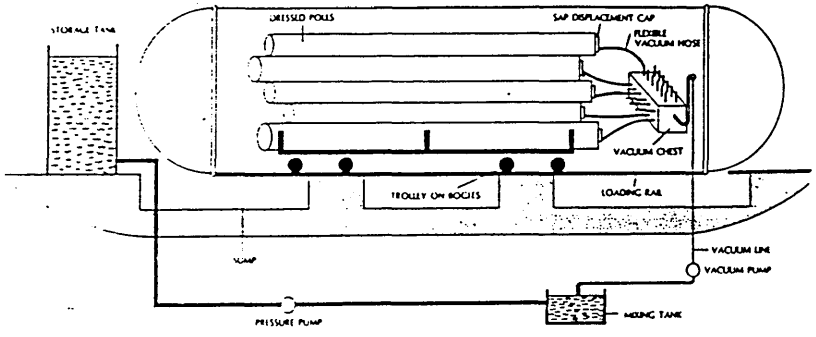
This paper examines in greater detail the concentration and radial distribution of copper, chrome and arsenic in Sitka and Norway spruce and Scots and Corsican pine poles treated with CCA by high pressure sap-displacement and exposed in the field for 12 months. The moisture content and severity of seasoning checks in pole species after 6 months field exposure are also examined. The purpose is twofold; to compare the treatment results and effects of field exposure between pole species and to discuss if the differences observed could affect their long term durability; secondly, to suggest improvements that could be made to the high pressure sap-displacement process to improve the treatment of Sitka spruce.

Materials and methods

Treatment of poles

Twenty, U.K. grown, 10 metre softwood overhead line supports [five poles of each of the following species, Sitka spruce (*Picea sitchensis* (Bong) Carr.); Norway spruce (*Picea abies* (L.) Karst.); Scots pine (*Pinus sylvestris* L.); and Corsican pine (*Pinus nigra* var. *maritima* Ait.)], were treated by sap-displacement within a conventional pressure cylinder (Fig 1a) using a 1.8 percent CCA type C solution. The poles were completely immersed in the preservative solution under a pressure of approximately 1000 kPa whilst a vacuum of -90 kPa was applied to one end of the individual poles using metal sap-displacement caps (Fig 1b). These conditions were maintained for up to 40 hours, the extracted sap being recirculated with the preservative solution.

(1a)



(1b)

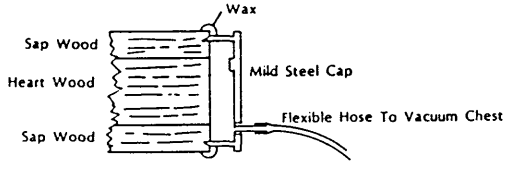


Fig 1. The pressure cylinder (a) and sap displacement cap (b) used in the high pressure sap-displacement process.

After treatment, the poles were air dried for 4 months and then planted in the ground (the butt of each pole being 1.5 metres below ground line) in Tealing, Scotland, in a modified latin square design (Fig 2).

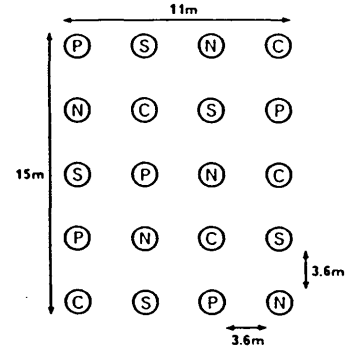


Fig 2. The arrangement of Sitka spruce (S), Norway spruce (N), Scots pine (P), and Corsican pine (C) poles in a modified latin square design.

Sampling and analysis of core samples for copper, chrome and arsenic

After 1 year of field exposure, each pole was sampled at ground line and 1 metre above ground by auger increment boring at 60 ° to the vertical. Four 140 mm long increment cores, two above ground, and two at ground line for each pole (4 x 20, 80 cores in toto) were removed and sectioned (Fig 3).

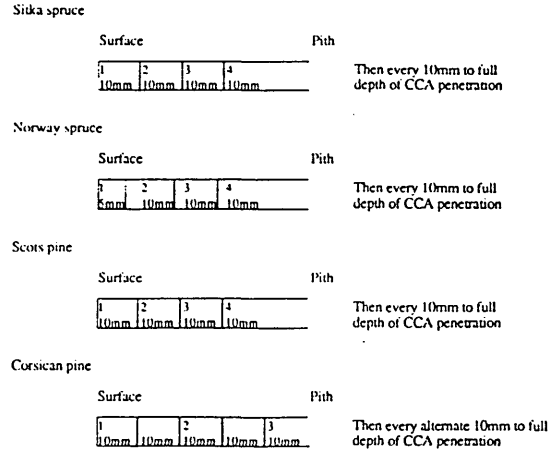


Fig 3. Sub-division of increment cores after boring.

A scalpel was used to reduce the core samples to fine slivers and the preservative content of these was determined by leaching the copper, chrome and arsenic compounds from the wood using a mixture of 2.5M sulphuric acid and 100 volume hydrogen peroxide (British Standards Institution 1979). The resulting solutions after addition of 3% w/v sodium sulphate solution were then analysed quantitatively using atomic absorption spectrophotometry (Williams 1972).

Statistical analysis of data

The mean concentrations of copper, chrome and arsenic in each core up to the depth of maximum CCA penetration were calculated and then used independently in analyses of variance (ANOVA) where pole species and the effect of core sample position (groundline or above) were the main factors of interest. Differences in the radial distribution of CCA elements between species was determined by calculating linear regression values for the relationship between the natural logarithms of core sample metal concentration and the natural logarithms of core sample depth. These values for each metal element were then subjected to separate ANOVAs as above. The back transformed antilog of the regression values are presented as regression slopes (%ww mm^{-1}). The method of least significant differences was used to evaluate the significance of differences in core metal concentration and linear regression values between species and between positions for individual species.

Checking and moisture content determinations in pole species

Check dimensions after 6 months field exposure were measured on each pole from groundline to a height 1 metre above ground using a thin metal ruler graduated in mm. The severity of checking in pole species was assessed on the basis of check frequency and radial depth of penetration. Checks were subdivided into classes (± 5mm) on the basis of their radial depth but checks less than 10mm in depth were not recorded

Moisture content determination of pole species after 6 months field exposure was also undertaken. Each pole was sampled 1 metre above ground by auger increment boring at 60° to the vertical and a single increment core approximately 80-140 mm long was removed from each pole. These were subdivided into sections varying from 10-25 mm in length and the moisture content of these was then determined gravimetrically by oven drying at 105 ±1 °C (Browning 1967).

Results

Concentration of CCA in cores

The concentration of metal elements in cores (% w/w Cu, Cr, As) for each pole species at groundline and above are presented in Fig 4 a-c. Significant differences in the concentration of copper ($p<0.001$) chrome ($p<0.01$) and arsenic ($p<0.01$) occur between species (Table 1) and in accord with the findings of an earlier preliminary investigation on the poles 4 months after treatment (Evans et al 1987), the concentration of all three metal elements are significantly ($p<0.01$) lower in Sitka spruce than in the other species. The concentration of copper ($p< 0.01$) is also significantly higher in Scots pine than in Norway spruce and Corsican pine.

The effect of sample position (groundline v above) upon the concentration of copper, chrome and arsenic is significant ($p<0.05$) although of lesser importance than the effect of species (Table 1). In all species with the exception of copper and arsenic in Sitka spruce and chrome and arsenic in Corsican pine, the concentration of metal elements are higher at groundline than above (Fig 4) but the species x position interaction is insignificant ($p>0.05$) for all metal elements (Table 1).

Fig 4. The concentration of copper, chrome and arsenic at groundline and above in Sitka spruce (S), Norway spruce (N), Scots pine (P) and Corsican pine (C) cores.

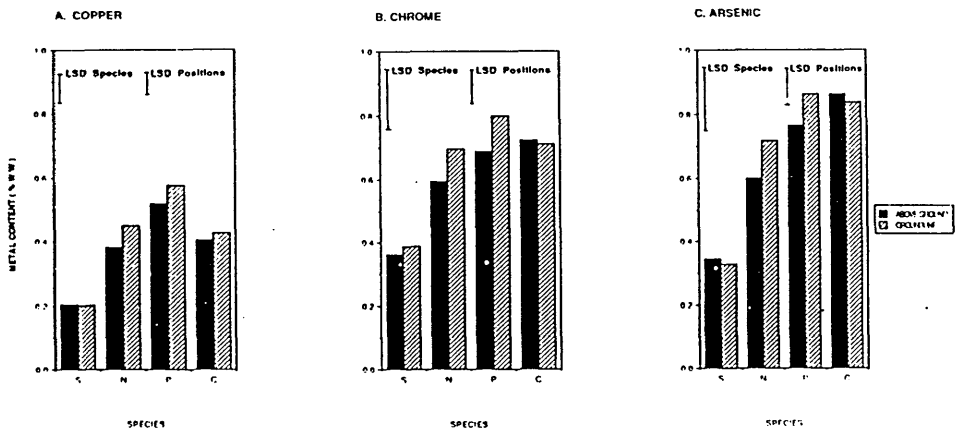


Table 1. Summary of the ANOVAs on the concentrations of copper, chrome and arsenic in cores.

Metal Element	Factors / Interactions	Degrees Freedom	F ratio	P
Copper	species	3	27.9	***
	position	1	5.2	*
	species x position	3	1.1	NS
Chrome	species	3	8.5	**
	position	1	5.2	*
	species x position	3	1.3	NS
Arsenic	species	3	11.1	**
	position	1	4.5	*
	species x position	3	1.2	NS

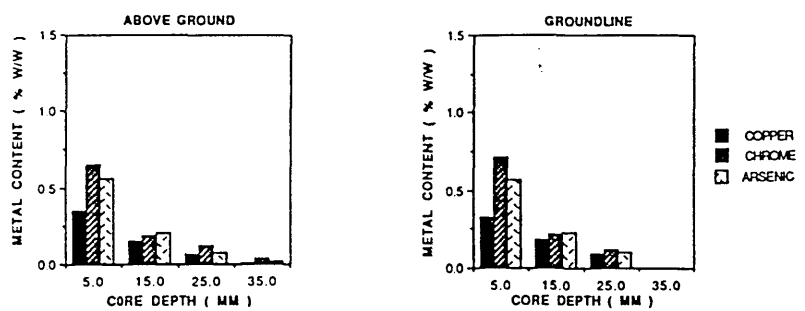
* indicates $p<0.05$; ** indicates $p<0.01$; *** indicates $p<0.001$; NS indicates $p> 0.05$.

Radial penetration and distribution of C.C.A.

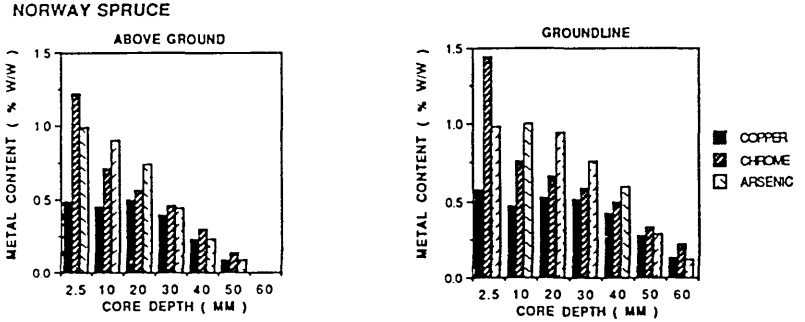
The radial penetration and distribution of copper, chrome and arsenic (%w/w, Cu, Cr, As) at groundline and above are presented in Fig 5 a-d. Maximum radial penetration of metal elements in Sitka spruce of 35mm are much lower than those found in Norway spruce (60mm), Scots pine (75mm) and Corsican pine (125mm). In all species, both at groundline and above, chromium reaches a maximum concentration in the outer sapwood and declines centripetally with increasing core depth. Similarly arsenic is also at a maximum concentration in the outer sapwood and declines centripetally with increasing core depth in Sitka spruce, Corsican pine and Norway spruce above ground. In contrast, in Scots pine and in Norway spruce at groundline the concentration of arsenic is lower in the outer than in the adjacent wood although thereafter it declines centripetally with increasing core depth. The radial distribution of copper varies between species and between positions (groundline v above) to a much greater extent than either chromium or arsenic. In Sitka spruce, copper is at a maximum concentration in the outer sapwood and declines centripetally with increasing core depth but in Corsican pine and in Scots pine and Norway spruce above ground, copper reaches a maximum concentration 45, 35, and 20mm respectively from the pole surface. At groundline in Norway spruce and Scots pine copper concentration is at a maximum in the outer sapwood but there are also secondary inner peaks in copper concentration.

Fig 5. Radial distribution of copper, chrome and arsenic at groundline and above in Sitka and Norway spruce and Scots and Corsican pine poles.

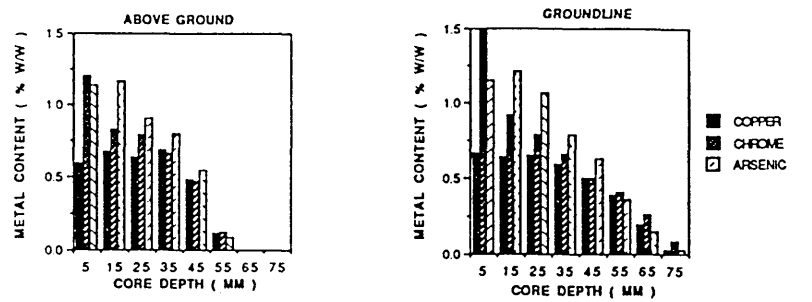
A. SITKA SPRUCE



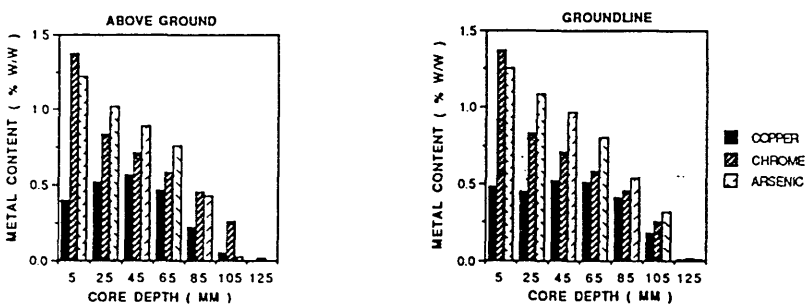
B. NORWAY SPRUCE



C. SCOTS PINE



D. CORSICAN PINE



Regression slopes representing the change in metal concentration with core sample depth are shown in Table 2. For all species, with the exception of arsenic at groundline in Scots pine and above ground in Corsican pine, chromium shows the largest (steepest) regression slopes. Arsenic shows similar regression slopes to chromium but the tendency of copper to reach high concentrations in the inner treated sapwood (Fig 5) is reflected by smaller (less steep) regression slopes. The ANOVAs on regression values (Table 3) reveal significant differences between species in the rate of change in copper ($p<0.01$) chrome ($p<0.001$) and arsenic ($p<0.001$) concentration with increasing core depth. Sitka spruce shows a significantly greater radial decrease in copper and chrome concentration than in Norway spruce ($p<0.05$), Scots pine ($p<0.05$) and Corsican pine ($p<0.001$).

Table 2. Regression slopes for copper, chrome and arsenic.

Species	Position	Slope (%ww mm^{-1}) Cu	Cr	As
Sitka spruce	Groundline	-0.0126	-0.0331	-0.0221
	Above ground	-0.0192	-0.0359	-0.0318
Norway spruce	Groundline	-0.0053	-0.0184	-0.0168
	Above ground	-0.0082	-0.0220	-0.0219
Scots pine	Groundline	-0.0061	-0.0203	-0.0229
	Above ground	-0.0086	-0.0210	-0.0199
Corsican pine	Groundline	-0.0018	-0.0097	-0.0080
	Above ground	-0.0037	-0.0084	-0.0093

The radial decrease in arsenic concentration is significantly($p<0.05$) greater in Sitka spruce than in Corsican pine. Interestingly, both Norway spruce and Scots pine show similar regression values for all metal elements but in Corsican pine relatively high concentrations of metal elements in the inner wood are reflected by significantly smaller regression values for copper ($p<0.05$) chrome ($p<0.01$) and arsenic($p<0.01$) than those found in Norway spruce or Scots pine.

Table 3. Summary of the ANOVAs on regression values for copper, chrome and arsenic.

Metal Element	Factors/Interactions	Degrees Freedom	F ratio	P
Copper	species	3	9.5	**
	position	1	20.5	***
	species x position	3	0.6	NS
Chrome	species	3	19.8	***
	position	1	0.3	NS
	species x position	3	1.0	NS
Arsenic	species	3	18.7	***
	position	1	3.5	NS
	species x position	3	1.6	NS

* indicates $P<0.05$, ** indicates $p<0.01$, *** indicates $P<0.001$, NS indicates $P>0.05$.

The effect of sample position (groundline v above) on regression values are significant ($p<0.001$) only for copper where above ground where there are larger radial decreases in metal concentration with increasing core depth than those found at groundline. As for the ANOVAs on metal concentration (Table 1) the species x position interaction on regression values is insignificant ($p>0.05$) for all metal elements.

Checking and moisture content of pole species

Checking is more frequent in Sitka and Norway spruce than in Scots and Corsican pine (Fig 6). In Sitka spruce, checks in excess of 40mm clearly exceed the depth of maximum preservative penetration of 35mm (Fig 5). In Norway spruce the maximum check depth is 35mm but checks do not penetrate the preservative treated annulus. In both Scots pine and Corsican pine checks occur infrequently and in accord with Norway spruce do not penetrate the preservative treated annulus.

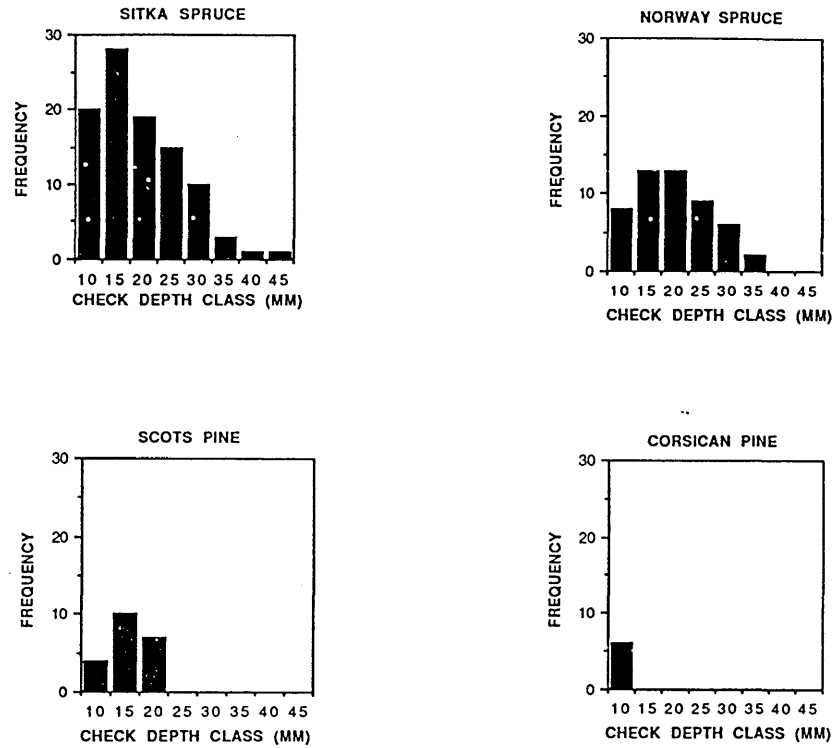


Fig 6. The frequency and depth of checking above ground in Sitka and Norway spruce and Scots and Corsican pine poles.

The moisture contents of increment core samples removed from the pole species above ground after 6 months field exposure are shown in Fig 7 a-d. In Norway spruce, Scots pine and Corsican pine, pole moisture content are around the fibre saturation point (FSP) and there is little variation in moisture content with increasing core depth. In contrast, moisture contents in Sitka spruce are higher particularly in the inner heartwood leading to a steep moisture gradient between the outer and inner wood.

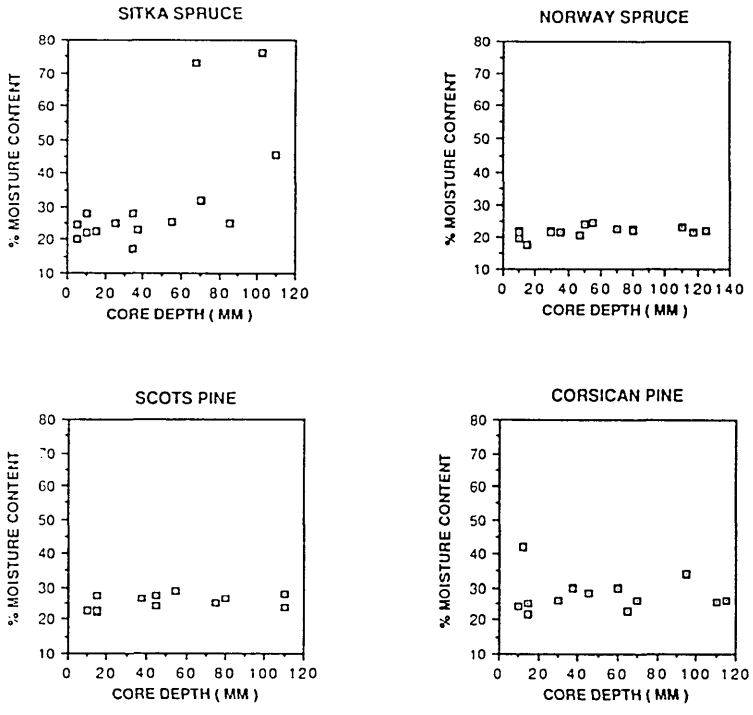


Fig 7. The above ground moisture content of core samples removed from Sitka and Norway spruce and Scots and Corsican pine poles.

Discussion

After 1 years field exposure the concentration of metal elements in cores with the exception of copper in Scots pine do not differ significantly in Norway spruce, Scots pine and Corsican pine but are significantly lower in Sitka spruce. In addition there is reduced penetration of CCA in Sitka spruce compared to the other species. Both spruce species but particularly Sitka spruce also show more severe checking compared to the pine species. In Sitka spruce these checks exceed the depth of maximum preservative penetration thus greatly increasing the chance of premature decay in field exposed poles since micro-organisms have access to wood which is both non durable (Evans et al 1988) and above FSP. The probability of such decay could be reduced in Sitka spruce by increasing depth of CCA penetration or by reducing its tendency to check severely. Previous methods of improving the retention and penetration of preservatives in Sitka spruce poles have used ponding prior to treatment (Dunleavy et al 1973) but such techniques have not found widespread application. Other possibilities exist, increased preservative penetration could simply be achieved by treating poles obtained from trees with large sapwood diameters and the positive correlation between tree crown class and sapwood volume in spruce (Büsgen and Münch 1929) could perhaps be used in the forest as the basis for selecting trees for subsequent conversion to poles. The latter approach could be simplified by using site index rather than foliage mass as the basis for pole selection since generally the more favourable the climate and the site the greater the percentage of sapwood rings in conifers (Chalk 1951; Trendelenburg and Mayer-Wegelin 1955).

Alternatively it may be possible to increase the depth of available, treatable sapwood by reducing sapwood losses that occur in the peeling of poles prior to treatment. These losses can be considerable, for example, comparison of two different commercially available peelers used in Australia for the peeling of radiata pine (*Pinus radiata* D. Don) posts prior to preservative treatment (Koppers-Hicksons 1989) revealed that sapwood losses differed by as much as 4mm. Increased sapwood losses can also occur as a result of the peeling of eccentric logs and thus these are particularly unsuitable for conversion into poles.

The use of oxide CCA formulations rather than the sulphate CCA used here could possibly increase the penetration and retention in Sitka spruce achieved by high pressure sap-displacement since a comparison of the penetration and absorption of sulphate and oxide CCA in six conifers after a modified full cell process (Kumar and Morrell 1989) showed that of the formulations tested the oxide CCA was associated with the highest retention and deepest penetration. Oxide CCA formulations also show a reduced tendency to form organo-metallic sludges in treatment plants (Mutandadzi and Evans 1990) and their use during sap-displacement could possibly minimize sludging, which due to the prolonged contact between the sulphate CCA and the green poles during treatment, is often excessive.

The problem of severe checking in Sitka spruce could also be reduced by using modified CCA formulations. CCA's containing bulking agents such as polyethylene glycol (PEG), (Trumble and Messina 1986) or wax hydrophobes (Koppers-Hicksons 1989) are reported to reduce the tendency of treated wood to check during exterior exposure and similar effects are also claimed for CCA-oil emulsions (Chin et al 1986). Kerfing prior to preservative treatment (Graham 1973), is used in the USA to reduce the severity of seasoning checks and the incidence of premature decay in treated poles but it is clearly unsuitable for use with high pressure sap-displacement since this process requires close contact between sap-displacement caps and the entire pole cross section during treatment.

Checking in Sitka spruce appears to be associated with high heartwood moisture contents and hence steep moisture gradients between the pole surface and the inner wet core. High heartwood moisture contents were also found in Sitka spruce 4 months after high pressure sap-displacement (Evans 1985) suggesting that the moisture profiles found here arise from the slow post treatment drying of Sitka spruce heartwood rather than from the ingress of water into heartwood through seasoning checks. Steep moisture gradients and hence stress gradients produce severe checking of CCA treated radiata pine during kiln drying (Mackay 1973) and may be alleviated by more careful drying after treatment or by applying bulking agents to the wood surface. A similar approach could perhaps also minimize the severity of checking in Sitka spruce here.

In Sitka spruce metal elements reach their highest concentration in the outer (0-10 mm) sapwood and decrease centripetally with increasing core depth. Higher concentrations of CCA in the outer sapwood of treated poles are necessary to provide protection at the soil /pole interface where soft rot is initiated. In addition for effective long term protection the initial concentration of CCA must be sufficient, allowing for depletion (Henningsson 1982) and detoxification (Butcher 1971) of CCA which occurs with field exposure, to remain above the toxic threshold for decay. The results here suggest that the latter criteria is not satisfied in Sitka spruce since the concentration of copper is only marginally above 0.2%, the value suggested as the toxic threshold for the decay of softwoods by soft rot fungi, (Nilsson 1982). Higher sapwood retentions of CCA are achieved in conventional pressure processes by increasing the concentration of CCA used in treatment but it was found that this resulted in increased sludging with the high pressure sap-displacement process (Fowlie 1985). Oxide CCA could possibly be used to achieve higher sapwood retentions in Sitka spruce since they are less susceptible to sludging (Mutandadzi and Evans 1990) and hence could be used at higher solution concentrations with the high pressure sap-displacement process.

In all species with the exception of copper and arsenic in Sitka spruce and chrome and arsenic in Corsican pine, the concentration of metal elements in cores are higher at

groundline than above. The regression slopes for copper in all species are also significantly smaller (less steep) at groundline than above. Earlier analysis of 8 of the poles examined here (2 poles for each species; Evans et al 1987) 4 months after high pressure sap-displacement revealed little longitudinal variation in CCA concentration. The differences in CCA distribution observed previously (Evans et al 1987) and here support the suggestion (Hainey et al 1989) that some re-distribution of CCA, and particularly copper, may occur in poles with field exposure but the results here also indicate that such effects are small in comparison to the differences in preservative retention and distribution arising between species due to the initial treatment.

In Norway spruce the concentrations of chrome and arsenic and their distribution are similar to that found in Scots pine but the concentration of copper is lower. In addition, Norway spruce has a greater tendency to check with field exposure. Nevertheless the results here suggest that high pressure sap-displacement is probably suitable for the treatment and long term protection of Norway spruce. Pine is readily treated by conventional pressure processes and the results here also indicate that it can be adequately treated by high pressure sap-displacement. The latter may however be more appropriate for the treatment of Corsican pine poles since in contrast to conventional treatments its use avoids prolonged drying periods and decay prior to treatment.

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THE INTERNATIONAL RESEARCH GROUP ON WOOD PRESERVATION

Working Group II Fundamentals of Testing

Studies in an accelerated soil bed facility on the decay susceptibility of U.K. grown spruce and pine poles treated with copper/chrome/arsenic (CCA) by pressurised sap-displacememt.

1. Setting up of soil beds and initial soft rot results.

by

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13 March 1990

Studies in an Accelerated Soil Bed Facility on the Decay Susceptibility of U.K. Grown Spruce and Pine Poles Treated with Copper/Chrome/Arsenic (C.C.A) by Pressurised Sap-Displacement.

1. Setting up of soil beds and initial results of soft rot studies.

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Summary

The paper describes the methodology used in the construction and early operation of an accelerated soil bed facility used to examine the decay susceptibility of U.K. grown Scots and Corsican pine and Sitka and Norway spruce treated with C.C.A. by high pressure sap-displacememt. The design and control of the facility as well as the preparation, soil exposure and soft rot decay analysis of quarter pole sections removed from full length poles is described in detail. The extent of soft rot in treated sections and controls was measured mechanically using a Pilodyn and also microscopically. In untreated control sections the Corsican pine was found to be the most susceptible timber to decay with the spruce species comparing favourably with Scots pine. All four treated wood species showed varying levels of C.C.A. penetration and subsequent resistances to decay. Thus while no soft rot decay was found in the treated regions of any of the wood species, internal soft rot was found beyond the penetration of the C.C.A. preservative. The implications of the findings for the testing of U.K. grown timber species for use as distribution poles after sap-displacement treatment with C.C.A. are discussed.

Keywords :- Accelerated testing; Distribution poles; Soft rot; U.K. grown timbers; Corsican pine; Scots pine; Sitka spruce; Norway spruce; CCA treatment; Sap-displacement.

Introduction

A wide variety of accelerated laboratory based systems have been used for the routine testing of both preserved and unpreserved wood blocks as a means of examining the suitability of a particular wood type or preservative formulation for service use. The most realistic method of testing timber products is lengthy field trials in a variety of geographic or climatic locations but this is not practical due mainly to constraints of time and expense. Laboratory based methods accelerate decay rates compared with field testing and can often give good comparative evaluation of the performance of formulations and of treated and untreated timbers. Such studies are not without their limitations however, and have been criticised as being of little value in predicting 'in service' field performance (Gersonde and Becker, 1958; Anon., 1978). Furthermore it is highly debatable whether the microbial ecology of wood in soil or exposed to pure cultures of fungi in laboratory systems can be expected to represent accurately the decay hazard to wood under the natural environmental conditions of the field. Another major limitation of traditional laboratory test methods is that the small wood specimens used often bear little size or structural similarity to the finished wood product in use in service.

To provide a less time consuming alternative to the reliable but expensive long term field trials a number of workers have reported experiments using intermediate systems (Gersonde and Becker, 1958); Deppe and Gersonde, 1977; Forest Research Institute, 1978; Hedley, 1980, 1983; Johnson et al, 1982; Clubbe, 1983; Vinden et al, 1982.)

The earlier researchers (Deppe and Gersonde, 1977), called these facilities 'fungal cellars' and used them to expose large dimension timbers to monocultures of basidiomycete fungi in sterilized soil. Many of the systems developed subsequently did not employ a pure culture of organisms but exposed wood samples to a natural soil microflora under carefully controlled environmental conditions. Hedley (1980, 1983) retained the term fungal cellar, but Johnson et al (1982) suggested that the term 'Accelerated Field Simulator' was more appropriate while Vinden et al (1982; 1983 a and b) described the use of 'soil-beds'.

These systems have a number of advantages over the conventional laboratory test methods, as outlined by Johnson et al (1982). Most importantly they allow the use of more representative timber specimens to be tested while still retaining the acceleration of the decay process found in laboratory test systems. Hedley (1983) found decay rates were between 7-12 times faster than for similarly treated samples exposed under field conditions. Further studies similar to those undertaken by Clubbe (1983) are required however, before it can be determined whether the ecology of decay in soil beds in anyway represents those found under field conditions.

The use of home grown timber species, (including Corsican and Scots pine and Norway and Sitka spruce) as overhead line supports has become increasingly attractive to the Electricity Supply Industry in the U.K. (Fowlie, 1981). The spruces are however difficult to treat by the traditional empty cell pressure preservation methods normally used for poles in the U.K. (Smith and Cockcroft, 1961) due largely to their impermeability (particularly Sitka spruce). Since conventional pressure impregnation does not appear suitable for spruce, research has concentrated on methods of improving preservative penetration either by increasing the permeability of the timber (eg. ponding, incising) or by the use of alternative preservation processes (Fowlie and Sheard 1983). As part of the latter approach high pressure sap-displacement of the wood poles with copper-chrome arsenic (C.C.A.) preservatives has been evaluated at this laboratory (Evans et al. 1987).

Pressurised sap-displacement has been long used in Denmark for the treatment of Norway spruce and Silver fir (Abies alba Mill) poles with C.C.A. (Shorland and Mason, 1974). An added attraction of sap-displacement in addition to improved preservative penetration is that unlike traditional pressure processes the wood can be treated soon after felling thereby avoiding extended drying periods during which pre-treatment decay may occur especially in non durable species such as Corsican pine.

A necessary prerequisite for the acceptance of poles treated with C.C.A. by high pressure sap-displacement is information on their decay susceptibility. An earlier paper (Evans et al 1988) examined the decay susceptibility of untreated U.K. grown spruce and pine in the laboratory to a mixed soil microflora. In this paper the construction and early operation of an accelerated soil-bed facility to examine the decay susceptibility of large sections removed from U.K. grown spruce and pine poles treated with C.C.A. by sap-displacement is described.

Materials and Methods

1. Preparation of the accelerated soil-bed facility.

A concrete encased room approximately 82m in volume in the basement of Dundee Institute of Technology was used to house the facility. Every effort was made to completely seal the room from the adjacent rooms to facilitate the control of temperature and humidity. The room contains 18 domestic black polypropylene water tanks (Merlin Ltd) 70cm x 100 cm x 70cm, which when filled with soil act as separate soil-beds (Figure 1). Each soil-bed tank has 16 drainage holes at the bottom and is filled to a depth of 410mm with graded soil material. The bottom 110mm of each soil-bed consists of course stones and gravel embedded in sand. Immediately above this is a layer of 110mm of stone free soil. The top layer is 190mm deep and contains soil which has all been passed through a 2mm sieve. The soil used in the tanks was non sterile, regularly fertilized sandy loam agricultural top soil supplied by the Scottish Crop Research Institute, Invergowrie, Dundee. Each soil-bed was covered with a 3mm thick sheet of perspex (750mm x 1050mm) supported on the plastic tanks by strips of PVC foam rubber (600mm and 800mm long respectively) to raise and maintain the humidity in the vicinity of the wood sections. Since the foam strips were not continuous along the entire length of the top edges of the plastic tanks, sufficient air was still able to reach the surface of the soil and wood sections.

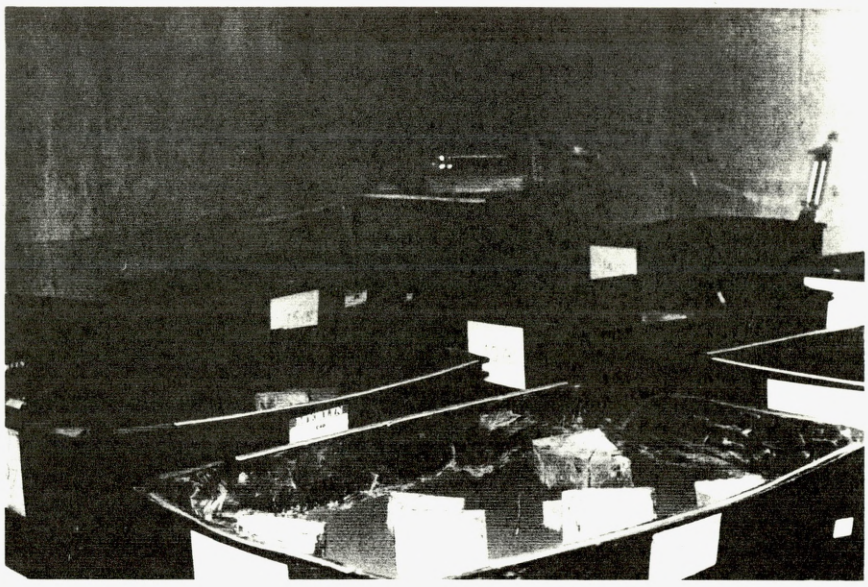

Figure 1:- Photograph showing accelerated soil bed facility with buried pole sections present in the individual soil beds.

Temperature and humidity in the facility were monitored every 2-3 days using wet and dry thermometers and were maintained at 26-28.5°C and 75-85% respectively by the action of two 1.5kW garden glasshouse fan heaters (Autogrow Greenhouse Heater E2R) placed at opposite ends of the room continuously blowing hot air over trays of water. In addition an Xpelaire humidifer (model no.EH 10) was placed in the centre of the room. While the humidity in the room was within the limits stated above beneath the perspex, ie. above the soil beds, it was between 95-100%.

Soil moisture within the soil-bed was set up at 100% of the soils W.H.C. as determined by the method of Savory and Carey (1973) and maintained at this value by the addition of water to the surface of the tanks if and when required. Moisture content of the soils was monitored using a garden moisture meter probe (Camplex plantcare moisture meter, model no. HD 500 M, Bentall Simplex Ltd.), previously calibrated to the %W.H.C. of the soil, which was inserted to the desired depth in the soil-bed. During the setting up and early use of the facility it was necessary to add water at regular intervals of approximately 4-7 days by careful spraying over the surface of the soil. After 6 weeks of operation however, a more stable equilibrium was reached and since then the soil-beds have been watered only every 8-10 weeks.

2. Monitoring of soil decay potential

As a check on the decay potential of the soil-beds four small untreated lime (Tilia vulgaris Hayne) blocks (20 x 10 x 5 mm) were buried, at a depth of 80mm in each of the 18 soil bed tanks. These were uplifted after a six week burial period and used for weight loss determination. After the facility had been in operation for 5, 16 and 23 months, further sets of small lime blocks were buried and uplifted after six weeks to monitor the continued decay activity of the soil.

3. Preparation of the wood sections.

Full length poles (10m) of Scots pine (Pinus sylvestris L.); Corsican pine (Pinus nigra var maritima Ait); Sitka spruce (Picea sitchensis (Bong) Carr); and Norway spruce (Picea abies L. Karst.),up to 300mm in diameter, were treated with a 1.8% C.C.A. Type C preservative by pressurised sap displacement (Evans et al 1987). Poles were treated in a conventional treatment cylinder over a 40 hour period under an applied pressure of 1000 kPa whilst a vacuum (-90 kPa) was applied to each individual pole through a metal cap attached to the ends of the individual poles. Control sections were treated by the same sap displacement process except that water was used instead of the C.C.A. solution. After treatment and allowing adequate time for fixation the poles were air dried for 6 months and cut into quarter pole sections approximately 200-280mm in length. The two radial longitudinal section (R.L.S.) faces of the sections were then sealed with two coats of a polystyrene resin (Scott Bader Co Ltd. Northhamptonshire, England) to ensure that, in accord with field exposed poles, only the tangential faces of the sections would be exposed to soil. The lower transverse section (T.S.) face of each section was also coated with resin to avoid possible waterlogging of the sections.

After coating, a single natural check in each of the pole sections was widened using a metal wedge to provide an avenue through the treated sapwood into the untreated heartwood . These checks were kept open (approximately 5mm wide) during soil burial by the insertion of small perspex spacers and were used to simulate the presence of seasoning checks in field exposed poles since colonisation and subsequent decay of poles is facilitated by check presence which allows access of micro-organisms to untreated sapwood or heartwood.

Preliminary studies on a small number of dry sections indicated that moisture uptake by the end sealed sections when buried in the soil-beds was slow and that they would take a long time to reach moisture contents suitable for decay. Consequently prior to soil exposure all the sections were wet up by submerging the sections in tap water to a moisture content of approx 30% w/w on an original dry weight basis. Immediately after wetting the sections were buried to a depth of 150 mm. in the soil beds. Each soil-bed contained eight pole sections spaced at approximately 200mm from each other and the same distance from the sides of the tanks. Sections were placed into the individual soil beds in a random manner to ensure that every soil-bed contained two sections of each wood species both of which would be removed at different sampling periods. The pattern of sampling also ensured that at least one, and a maximum of two control sections of any species would be present in each soil-bed.

4. Sampling and soft rot measurement.

After six and twelve months exposure wood sections were removed from the soil-beds for chemical and biological analyses. Five treated and one untreated control section of each wood species were uplifted at each sampling interval. Immediately after removal any adhering soil was removed and the sections were tested for surface softening using a Pilodyn with an impact energy of 2 Joules, (Cobra (Wood Treatment) Limited), a device previously used for detecting soft rot decay in standing poles (Friis-Hansen, 1980, 1981; Leightley, 1981, 1982). A template grid (300mm x 300mm) with 40 x 40 mm squares was placed over the tangential (curved) surface of each section and a pilodyn measurement (depth of needle penetration in mm) was recorded at the centre of each square.

In addition to the Pilodyn measurements a semi-quantitative technique was used to measure the severity of the soft rot attack at increasing radial depths into the sections. The method was a modification of the technique reported by Anagnost (1987) which involved microscopic examination of the wood fibres after partial chemical treatment. Small wood samples (5mm x 5mm x 1mm approx.) were removed at increasing depths (approximately every 2-4 mm) from the surface of the sections and boiled for 1 hour in 5mls of a 50/50 mixture of analar glacial acetic acid (17.4M) and hydrogen peroxide (100 vol) until defibration of the wood occurred (Franklin 1946). The individual tracheids were then examined microscopically (x150 magnification) under polarised light and the extent of soft rot cavity formation in each tracheid recorded. Four categories were used to record the decay severity within the individual tracheids as follows:-

0 - no soft rot cavities
1 - less than 50% of cell wall covered with cavities
2 - greater than 50% but less than 100% covered with cavities
3 - cell wall surface totally covered with large coalesced cavities or showing signs of splitting.

Twenty randomly selected fibres were examined at each sample depth and a 'Soft rot Decay Index' was calculated by adding together the scored results for the twenty fibres.

Pole sections were sampled at the two points on the tangential (curved) face which had previously given the highest readings with the Pilodyn.

In addition to the soft rot measurements reported here various other biological and chemical analyses were undertaken. These included wood moisture and soil dehydrogenase determinations; analysis of copper, chromium and arsenic levels; and measurement of internal decay produced by direct colonisation of organisms from soil through checks or by artificial inoculation with basidiomycetes. The results of these additional studies will be reported later (Hainey 1990).

Results

Weight loss results for the small, untreated, buried lime blocks (Table 1) over the first twenty four months of operation indicate that conditions within the soil beds were suitable for decay.

Date of burial of blocks	Time of burial (months)	Mean % weight loss
1/4/87	1	41.2 ± 8.7
4/8/87	5	52.9 ± 11.3
23/6/88	16	42.6 ± 9.8
26/1/89	23	39.2 ± 6.7

Weight loss figures represent the mean for all blocks from 18 soil beds (72 blocks in toto at each sampling period).

Table 1.:- Mean weight losses of untreated lime blocks after six weeks burial in soil beds. Time of burial is time from initial operation of soil bed facility (2/3/87) after which the blocks were buried.

On removal of the sections from the soil beds it was noticeable, particularly at the earlier sampling times, that the most obvious surface soft rot decay was present on the untreated pines especially the Corsican pine with less surface softening associated with the two spruce species. No obvious signs of surface decay was visible in any of the CCA treated sections.

The results of Pilodyn measurements from both CCA treated and untreated sections are presented in Table 2. Again these indicate that satisfactory levels of decay were achieved in the soil bed system. Although the instrument is able to detect the presence of decay in the untreated control sections after six months and can be used to monitor progressive increases in soft rot severity, the device was not sensitive enough however to detect the differences in the extent of the soft rot attack in the different wood species. The protective effect of the CCA treatment can, however, be seen by comparing Pilodyn readings for CCA treated and untreated sections after continued soil exposure.

Burial period (months)	Pilodyn readings for Untreated sections (mm penetration)	Pilodyn readings for curved faces of CCA treated sections (mm penetration)	
0	9.1 ± 0.6	7.4 ± 1.2	
6	12.4 ± 2.2	8.8 ± 1.3	
12	16.9 ± 2.2	8.3 ± 0.4	Corsican Pine
18	17.8 ± 2.0	7.5 ± 0.3	
24	19.8 ± 3.0	9.5 ± 0.6	
0	10.8 ± 0.2	7.4 ± 1.2	
6	15.8 ± 1.3	9.5 ± 0.3	
12	15.9 ± 1.8	9.4 ± 1.2	Scots Pine
18	22.6 ± 1.5	8.8 ± 0.5	
24	22.1 ± 2.8	9.9 ± 0.7	
0	7.4 ± 0.1	7.5 ± 0.5	
6	13.9 ± 2.1	8.9 ± 0.8	
12	16.6 ± 1.9	9.2 ± 0.2	Norway Spruce
18	21.0 ± 2.6	9.1 ± 0.4	
24	19.1 ± 3.7	9.6 ± 0.8	
0	5.9 ± 0.5	7.5 ± 1.0	
6	13.6 ± 1.5	7.9 ± 0.8	
12	10.2 ± 2.0	8.6 ± 0.8	Sitka Spruce
18	17.3 ± 1.6	8.4 ± 0.7	
24	21.9 ± 1.9	8.9 ± 1.2	

Table 2. :- Pilodyn measurements for exposed surfaces of both untreated and CCA treated pole sections. (Note 0 time control sections were wet up to 30% moisture content prior to Pilodyn sampling).

Soft rot decay indices produced after microscopic analysis of large untreated control samples (Figure 2) also indicate satisfactory levels of decay in the soil bed system. Extensive soft rot cavitation is present in all species with the Corsican pine sections being particularly badly affected. For this species soft rot was recorded at a depth of 12mm after only six months burial.

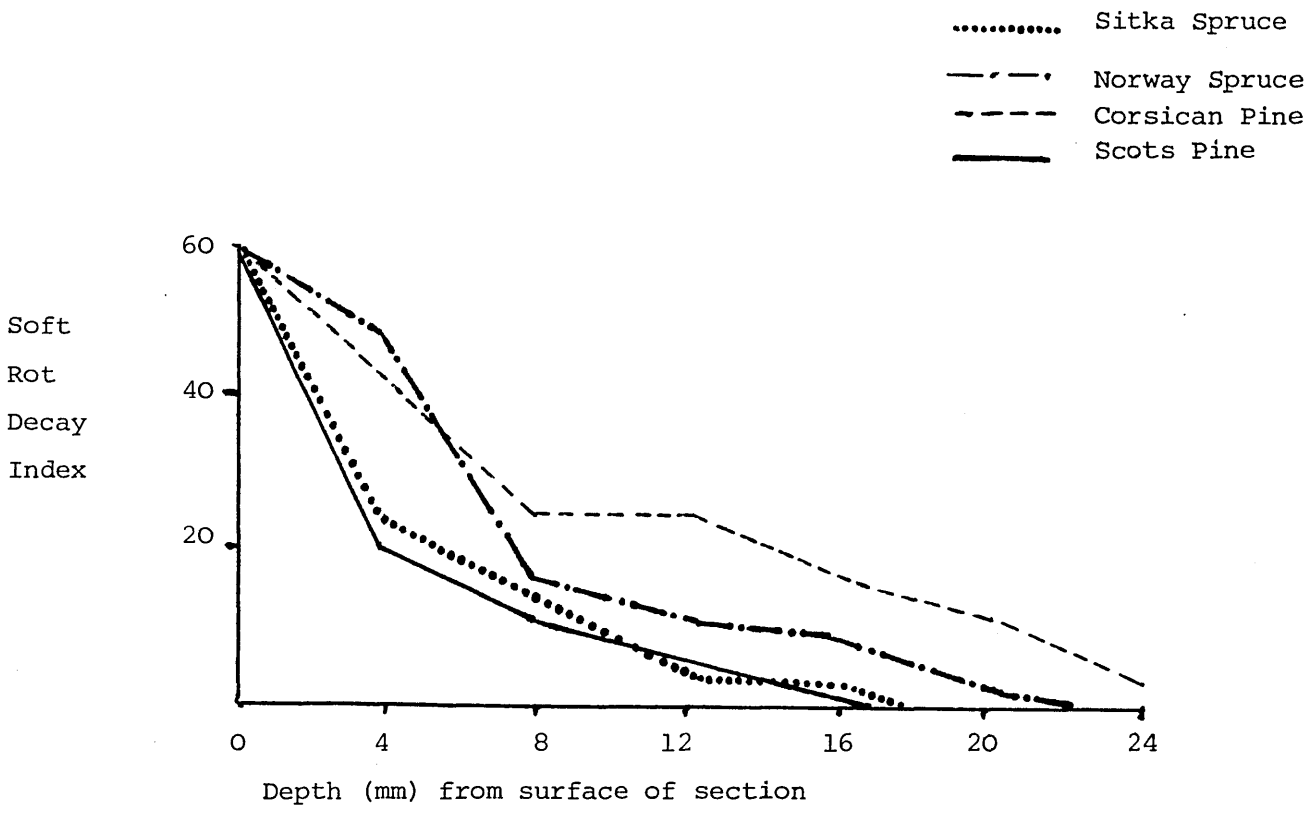

Figure 2:- "Soft Rot Decay Index" showing the severity of soft rot penetration in sections after 12 months soil exposure.

In contrast to the extensive depths of soft rot decay found in the control sections of all four wood species, no soft rot attack has been identified on the exposed tangential (curved) surfaces of any of the CCA sap displaced pole sections after 24 months burial in the accelerated soil bed facility.

Discussion

The weight losses produced in the small lime blocks indicate that the system, has a high decay potential and is operating successfully. After an initial period during which water was regularly and frequently added (every 4-7 days) to the soil beds to maintain them at the desired moisture content they reached a suitable state of equilibrium, with additional spraying required only infrequently (about every 8-10 weeks). No problems with soil or wood waterlogging or soil crusting as identified as potential problems in accelerated soil bed systems by Johnson et.al. (1982) have been encountered during this study. Although small inter tank variations were observed in both moisture contents and weight losses in small lime blocks after burial, in no single tank were conditions limiting to decay. Indeed the minimum mean weight loss of the four blocks in any single tank was 27% after six weeks burial.

A number of articles have examined and commented on the use of accelerated soil bed facilities and their advantages and disadvantages (Hedley, 1980,1983; Johnson et.al. 1982; Vinden et.al. 1983) but no direct comparison between the decay hazard in such facilities and the field can be made since little work on the microbial ecology of the former has been undertaken. While there is little doubt that wood decay rate is accelerated in the soil bed systems compared with the field tests it is most unlikely that the microflora of soil in a soil bed system is subjected to the same fluctuating environmental pressures as that of a field test site soil. Consequently it is reasonable to expect that the wood placed in soil under such conditions may be exposed to an entirely different type of soil microflora. For this reason it is not really realistic to calculate acceleration factors for fungal cellars over field tests and it is even more speculative to extrapolate field performance from soil bed results. The choice of the term "Accelerated field simulator" to describe a soil bed test facility is perhaps an unfortunate one since while these test systems do supply many of the advantages associated with field testing they cannot reasonably be described as simulating all the conditions present in the field. More recently Ruddick (1989) has attempted to re-define the role of the "fungal cellar" in the testing of wood and wood products.

While it is obvious from the microscopic analysis of the wood fibres that the severity and extent of invasiveness of the soft rot is most severe in the untreated Corsican pine, this species effect was not detected using the pilodyn. Leightly (1986) found a good correlation between the amount of soft rot (measured microscopically at various depths from the surface) and Pilodyn readings in CCA treated Eucalypt distribution poles. The results of that study and those reported earlier (Friis-Hansen,1980; Leightley, 1982) showed that a 6 Joule Pilodyn unit was found to provide the required sensitivity in detecting external pole decay. For poles made from more dense wood species however, Friis-Hansen (1980) recommended the use of a 12 Joule Pilodyn. The failure of the Pilodyn (2 Joules) to detect differences in depth of soft rot decay in species tested in this study may therefore simply have been due to differences in the densities of the timber species tested and a lack of penetrating power associated with the use of a less powerful pilodyn.

The variability in extent of surface soft rot decay among the four untreated wood species in this study is similar to that reported by Evans et.al. (1988) who reported large species differences in decay susceptibility (measured by weight loss) of small sapwood blocks totally buried in unsterile soil. While these differences in decay susceptibility are almost certainly due to structural and compositional differences between the four wood species Evans.et.al.(1988) found no marked variations in the density of the sapwood of the four species which might account for the observed differences in their decay susceptibilities. Fungal colonisation and subsequent decay are influenced by the moisture content of the wood and while the moisture content of the soils in all soil beds was maintained at a regular level, the moisture profiles of the sections of various wood species were different (Hainey 1990). The extent to which untreated pine wood sections wet up was much greater than two spruce species. This is probably due to anatomical differences in the timbers including the extent of pit aspiration, with spruce species being well documented as being difficult to treat and a significant difference in the extent of pit aspiration between Corsican and Scots pine sapwood has also been reported (Phillips 1933 in Jane 1970).

A more important factor in determining the decay susceptibility of the wood species during soil exposure may be their nitrogen contents. Oxley et al. (1976) showed that the nitrogen content, particularly the soluble nitrogen content, accelerated soft rot decay in pine and spruce. While nitrogen analysis of the wood species has not been undertaken here King et al. (1976) reported that the nitrogen content of the outer sapwood of U.K.grown Scots pine (0.11%) was significantly higher than that of U.K. grown Sitka spruce (0.07%) and Waite (1977 unpublished data) recorded nitrogen contents in the outer sapwood of U.K. grown Corsican pine of 0.18% after drying. If similar nitrogen contents are present in the wood sections used in this current study they might largely account for the patterns of soft rot penetration reported here.

Evans et.al. (1987) reported that the Scots and Corsican pine and Norway spruce poles, sap displaced with CCA as described in this study, contained significantly greater concentrations of CCA in the treated sapwood than Sitka spruce poles. Indeed the copper concentrations in the surface layers of Sitka spruce (0.14% w/w metal) were below the figure of 0.2% (w/w metal) reported by Nilsson (1982) as the toxic threshold for the decay of pinus spp. by soft rot organisms. Despite this no soft rot has been detected either microscopically or by pilodyn measurements within the treated regions on the tangential surfaces of Sitka spruce sections after 24 months incubation.

Internal pockets of soft rot have, however, been found in treated sections of Norway and Sitka spruce and Scots pine. These cavities have been associated with the artifically produced checks in the sections and have generally been located in the untreated heartwood regions. In a few Sitka spruce sections however, small internal pockets of soft rot were found within the treated region inside the checks after only 18 months soil exposure. CCA concentrations are much lower internally than at the pole surface due to the radial distribution pattern of the CCA salts produced during sap-displacement treatment (Evans et.al. 1987). Such internal soft rot has also been reported in CCA treated Telecommunication poles in Sweden after more than 20 years field service (Friis-Hansen and Lundstrom, 1989).

Since the results of this study and that reported in Hainey (1990) indicate that internal colonisation by soft rot and basidiomycete fungi can take place through checks in treated pole sections it is obvious that if CCA treatment by sap-displacement is to be a viable alternative to pressure treatment of poles then a good deep, even penetration of the salt must be achieved. This is particularly important with sap-displacement since unlike traditional pressure treatment the poles are not dried before treatment and hence any subsequent checks which may form might expose untreated timber. In contrast traditionally treated poles are dried prior to treatment and the surfaces of any checks which are produced may be treated with the preservative. From the results of this study it is obvious that Sitka spruce as treated here does not provide suitable protection from internal decay even though the surface levels of CCA salts have resisted decay.

Conclusion

It is obvious from the results presented here that the accelerated soil bed facility described can be a very useful test system for the analysis of the decay susceptibility of CCA treated distribution pole sections. The facility provides a test system which permits the use of large dimensioned representative timbers which is essential to any realistic study of the decay of treated distribution poles and yet still provides results within a reasonable timescale. While the test system cannot predict accurately the absolute field service life of the poles the results presented here clearly show that it provides an ideal test system for the comparative evaluation of different wood species for use as distribution poles and for testing various preservative treatments of such material.

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SOIL-BED DECAY STUDIES OF SOFTWOOD POLE SEGMENTS TREATED WITH CCA BY SAP-DISPLACEMENT

1. Evaluation of soil bed exposure and assessment of soft rot decay

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Keywords:- Accelerated testing; Distribution poles; Transmission poles; Soft rot; U.K. grown timbers; Corsican pine; Scots pine; Sitka spruce; Norway spruce; CCA treatment; Sap-displacement.

Abstract

This paper describes the methodology used in the construction and early operation of an accelerated soil-bed facility used to examine the decay susceptibility of U.K. grown Scots and Corsican pine and Sitka and Norway spruce treated with C.C.A. by high pressure sap-displacement. The design and control of the facility as well as the preparation, soil exposure and soft rot decay analysis of quarter pole sections removed from full length poles is described. The extent of soft rot in treated sections and controls was measured mechanically, using a Pilodyn, and microscopically. In untreated control sections Corsican pine was found to be the most susceptible timber to decay with the spruce species comparing favourably with Scots pine. All four treated wood species showed varying levels of C.C.A. penetration and resistance to decay. No soft rot decay was found in the treated regions of any of the wood species but internal soft rot decay was found beyond the penetration of the C.C.A. preservative. The implications of the findings for the testing of U.K. grown timber species for use as distribution poles after sap-displacement treatment with C.C.A. are discussed.

Introduction

A wide variety of accelerated laboratory based systems has been used for the routine testing of both preserved and unpreserved wood blocks as a means of examining the suitability of a particular wood type or preservative formulation for service use. The most realistic method of testing timber products is lengthy field trials in a variety of geographic or climatic locations but this is not practical due mainly to constraints of time and expense. Laboratory based methods accelerate decay rates compared with field testing and can often give good comparative evaluations of the performance of formulations and of treated and untreated timbers. Such studies are not without their limitations however, and have been criticised as being of little value in predicting 'in service' field performance (Gersonde and Becker, 1958; Anon., 1978) Furthermore it is highly debatable whether the microbial ecology of wood in soil or exposed to pure cultures of fungi in laboratory systems can be expected to represent accurately the decay hazard to wood under the natural environmental conditions of the field. Another major limitation of traditional laboratory test methods is that the small wood specimens used often bear little size or structural similarity to the finished wood product in use in service.

To provide a less time consuming alternative to the reliable but expensive long term field trials, a number of workers have reported experiments using intermediate systems (Gersonde and Becker, 1958; Deppe and Gersonde, 1977; Forest Research Institute, 1978; Hedley, 1980, 1983; Johnson *et al.*, 1982; Clubbe, 1983; Vinden *et al.*, 1982.)

The earlier researchers (Deppe and Gersonde, 1977), called these facilities 'fungal cellars' and used them to expose large dimension timbers to monocultures of basidiomycete fungi in sterilized soil. Many of the systems developed subsequently did not employ a pure culture of organisms but exposed wood samples to a natural soil microflora under carefully controlled environmental conditions. Hedley (1980, 1983) retained the term fungal cellar, but Johnson *et al.* (1982) suggested that the term 'Accelerated Field Simulator' was more appropriate while Vinden *et al.* (1982; 1983 a and b) described the use of 'soil-beds'.

These systems have a number of advantages over the conventional laboratory test methods, as outlined by Johnson *et al.* (1982). Most importantly they allow the use of more representative larger specimens while still retaining the acceleration of the decay process found in laboratory test systems. Hedley (1983) found decay rates were between 7 – 12 times faster than for similarly treated samples exposed under field conditions. Further studies similar to those undertaken by Clubbe (1983) are required however, before it can be determined whether the ecology of decay in soil-beds represents that found under field conditions.

The use of U.K. grown timber species, (including Corsican and Scots pine and Norway and Sitka spruce) as overhead line supports has become increasingly attractive to the Electricity Supply Industry in the U.K. (Fowlie, 1981). The spruces are however difficult to treat by the traditional empty cell pressure preservation methods normally used for poles in the U.K. (Smith and Cockcroft, 1961) due largely to their impermeability (particularly Sitka spruce). Since conventional pressure impregnation does not appear suitable for spruce, research has concentrated on methods of improving preservative penetration either by increasing the permeability of the timber (eg. by ponding or incising) or by the use of alternative preservation processes

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(Fowlie and Sheard, 1983). As part of the latter approach high pressure sap-displacement of wood poles with copper chromium arsenic (C.C.A.) preservatives has been evaluated at this laboratory (Evans *et al.*, 1987).

Pressurised sap-displacement has been long used in Denmark for the treatment of Norway spruce and Silver fir (*Abies alba* Mill) poles with C.C.A. (Shorland and Mason, 1974). An added attraction of sap-displacement in addition to improved preservative penetration is that unlike traditional pressure processes the wood can be treated soon after felling, thereby avoiding extended drying periods during which pre-treatment decay may occur, especially in non durable species such as Corsican pine.

A necessary pre requisite for the acceptance of poles treated with C.C.A. by high pressure sap-displacement is information on their decay susceptibility. An earlier paper (Evans *et al.*, 1988) examined the decay susceptibility of untreated U.K. grown spruce and pine in the laboratory to a mixed soil microflora. In this paper the construction and early operation of an accelerated soil-bed decay facility to examine the decay susceptibility of large sections removed from U.K. grown spruce and pine poles treated with C.C.A. by sap-displacement is described.

Materials and Methods

Preparation of the accelerated soil-bed facility

A concrete encased room approximately 82m^3 in volume in the basement of Dundee Institute of Technology was used to house the facility. Every effort was made to completely seal the room from the adjacent rooms to facilitate the control of temperature and humidity. The room contains 18 domestic, black, polypropylene water tanks (Merlin Ltd) 700 mm × 1000 mm × 700 mm, which when filled with soil act as separate soil-beds (Figure 1). Each soil-bed tank has 16 drainage holes at the bottom and is filled to a depth of 410 mm with graded soil material. The bottom 110 mm of each soil-bed consists of coarse stones and gravel embedded in sand. Immediately above this is a layer of 110 mm of stone-free soil. The top layer is 190 mm deep and contains soil which has all been passed through a 2 mm sieve. The soil used in the tanks was non-sterile, regularly-fertilized, sandy loam, agricultural top soil, supplied by the Scottish Crop Research Institute, Invergowrie, Dundee. Each soil-bed was covered with a 3 mm thick sheet of perspex (750 mm × 1050 mm) supported on the plastic tanks by strips of PVC foam rubber (600 mm and 800 mm long respectively) to raise and maintain the humidity in the vicinity of the wood sections. Since the foam strips were not continuous along the entire length of the top edges of the plastic tanks, air was able to reach the surface of the soil and wood sections.

Temperature and humidity in the facility were monitored every 2 – 3 days using wet and dry thermometers and were maintained at 26 – 28·5°C and 75 – 85% respectively by the action of two 1·5 kW garden glasshouse fan heaters (Autogrow Greenhouse Heater E2R) placed at opposite ends of the room continuously blowing hot air over trays of water. In addition an Xpelaire humidifier (model no. EH 10) was placed in the centre of the room. While the humidity in the room was within the limits stated above, beneath the perspex, ie. above the soil beds, it was betwen 95 and 100%.

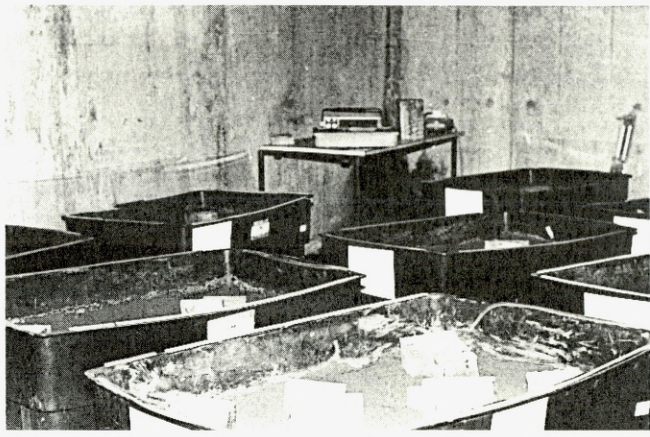

Figure 1. Photograph showing accelerated soil bed facility with buried pole sections present in the individual soil-beds.

Soil moisture within the soil-bed was set up at 100% of the soils water-holding capacity (W.H.C.) as determined by the method of Savory and Carey (1973) and maintained at this value by the addition of water to the surface of the tanks if and when required. Moisture content of the soils was monitored using a garden moisture meter probe (Camplex plantcare moisture meter, model no. HD 500 M, Bentall Simplex Ltd.), previously calibrated over a range of the W.H.C. of the soil, which was inserted to the desired depth in the soil-bed. During the setting up and early use of the facility it was necessary to add water at regular intervals of approximately 4 – 7 days by careful spraying over the surface of the soil. After 6 weeks of operation however, a more stable equilibrium was reached and since then the soil-beds have been watered only every 8 – 10 weeks.

Monitoring of soil decay potential

As a check on the decay potential of the soil-beds four small untreated lime (*Tilia vulgaris* Hayne) blocks (20 × 10 × 5 mm) were buried, at a depth of 80 mm in each of the 18 soil-bed tanks. These were uplifted after a six week burial period and used for weight loss determination. After the facility had been in operation for 5, 16 and 23 months, further sets of small lime blocks were buried and uplifted after six weeks to monitor the continuing decay activity of the soil.

Preparation of the wood sections

Full length (10 m) poles of Scots pine (*Pinus sylvestris* L.); Corsican pine ((*Pinus nigra var maritima* Ait); Sitka

spruce (*Picea sitchensis* (Bong) Carr); and Norway spruce (*Picea abies* L. Karst.), up to 300 mm in diameter, were treated with a 1·8% C.C.A. preservative by pressurised sap displacement (Evans *et al.*, 1987). Poles were treated in a conventional treatment cylinder over a 40 hour period under an applied pressure of 1000 kPa whilst a vacuum (−90 kPa) was applied to each individual pole through a metal cap attached to the ends of the individual poles. Control sections were treated by the same sap displacement process except that water was used instead of the C.C.A. solution. After treatment and fixation, the poles were air dried for 6 months and cut into quarter pole sections approximately 200−280 mm in length. The two radial longitudinal (R.L.) faces of the sections were then sealed with two coats of a polystyrene resin (Scott Bader Co Ltd. Northamptonshire, England) to ensure that, in accord with field exposed poles, only the tangential faces of the sections would be exposed to soil. The lower transverse face of each section was also coated with resin to avoid possible waterlogging of the sections.

After coating, a single natural check in each of the pole sections was opened using a metal wedge to provide an avenue through the treated sapwood into the untreated heartwood. These checks were kept open (approximately 5 mm wide) during soil burial by the insertion of small perspex spacers and were used to simulate the presence of seasoning checks in field exposed poles since colonisation and subsequent decay of poles is facilitated by check presence which allows access of micro-organisms to untreated sapwood or heartwood.

Preliminary studies on a small number of dry sections indicated that moisture uptake by the end sealed sections when buried in the soil-beds was slow and that they would take a long time to reach moisture contents suitable for decay. Consequently prior to soil exposure all the sections were wetted up by submerging the sections in tap water until a moisture content of approx 30% m/m on an original dry weight basis resulted. Immediately after wetting, the sections were buried to a depth of 150 mm in the soil-beds. Each soil-bed contained eight pole sections spaced at approximately 200 mm from each other and the same distance from the sides of the tanks. Sections were placed into the individual soil beds in a random manner, except that every soil-bed contained two sections of each wood species, each of which would be removed at different sampling periods. The pattern also ensured that at least one, and a maximum of two, control sections of any species would be present in each soil-bed.

Sampling and soft rot measurement

After six, twelve, eighteen and twenty four months exposure, wood sections were removed from the soil-beds for chemical and biological analyses. Five treated and one untreated control section of each wood species were uplifted at each sampling interval. However at time 'zero' two untreated controls and five treated sections were used. Immediately after removal any adhering soil was removed and the sections were tested for surface softening using a Pilodyn with an impact energy of 2 Joules, (Cobra (Wood Treatment) Limited), a device previously used for detecting soft rot decay in standing poles (Friis-Hansen, 1980, 1981; Leightley, 1981, 1982). A template grid (300 mm × 300 mm) with 40 × 40 mm squares was placed over the tangential (curved) surface of each section and a pilodyn measurement (depth of needle penetration in mm) was recorded at the centre of each square.

In addition to the Pilodyn measurements a semi-quantitative technique was used to measure the severity of the soft rot attack at increasing radial depths into the sections uplifted after six and twelve months. The method was a modification of the technique reported by Anagnost (1987) which involved microscopic examination of the wood fibres after partial chemical treatment. Small wood samples (5 mm × 5 mm × 1 mm approx.) were removed at increasing depths (approximately every 2−4 mm) from the surface of the sections and boiled for 1 hour in 5 mls of a 50/50 mixture of analar glacial acetic acid (17·4M) and hydrogen peroxide (100 vol) until defibration of the wood occurred (Franklin 1946). The individual tracheids were then examined microscopically (× 150 magnification) under polarised light and the extent of soft rot cavity formation in each tracheid was recorded. Four categories were used to record the decay severity within the individual tracheids as follows:-

0 — no soft rot cavities
1 — less than 50% of cell wall covered with cavities
2 — greater than 50% but less than 100% covered with cavities
3 — cell wall surface totally covered with large coalesced cavities or showing signs of splitting.

Twenty randomly selected fibres were examined at each sample depth and a 'Soft rot Decay Index' was calculated by adding together the scored results for the twenty fibres.

Pole sections were sampled at the two points on the tangential (curved) face which had previously given the highest readings with the Pilodyn.

In addition to the soft rot measurements reported here various other biological and chemical analyses were undertaken. These included wood moisture and soil dehydrogenase determinations; analysis of copper, chromium and arsenic levels; and measurement of internal decay produced by direct colonisation of organisms from soil through checks or by artificial inoculation with basidiomycetes. The results of these additional studies will be reported later (Hainey, 1991).

Results

Weight loss results for the small, untreated, buried lime blocks (Table 1) over the first twenty four months of operation indicate that conditions within the soil-beds were suitable for decay.

TABLE 1 **Mean weight losses and standard deviations of untreated lime blocks after six weeks burial in soil-beds. *Time of burial is time from initial operation of soil bed facility (2/3/87) after which the blocks were buried.**

Date of burial of blocks	Time of burial* /months	Mean % weight loss
1/4/87	1	41·2 ± 8·7
4/8/87	5	52·9 ± 11·3
23/6/88	16	42·6 ± 9·8
26/1/89	23	39·2 ± 6·7

Weight loss figures represent the mean for all blocks from 18 soil beds (72 blocks in total at each sampling period).

On removal of the sections from the soil-beds it was noticeable, particularly at the earlier sampling times, that the most obvious surface soft rot decay was present on the untreated pines especially the Corsican pine with less surface softening associated with the two spruce species. No obvious signs of surface decay were visible in any of the CCA treated sections.

The results of Pilodyn measurements from both CCA treated and untreated sections are presented in Table 2. These. together with the microscopic analysis of the same sections, indicate that satisfactory levels of decay were achieved in the soil bed system. Although the instrument is able to detect the presence of decay in the untreated control sections after six months and can be used to monitor progressive increases in soft rot severity, the device was not sensitive enough to detect the differences in the extent of the soft rot attack in the different wood species. The protective effect of the CCA treatment can, however, be seen by comparing

TABLE 2 **Pilodyn measurements and standard deviations for exposed surfaces of both untreated (approx. 15 replicate measurements) and CCA treated (approx. 75 replicate measurements) pole sections. (All sections were equal to or above 30% moisture content prior to Pilodyn testing).**

Burial period/ months	Pilodyn readings for Untreated sections/mm penetration	Pilodyn readings for curved faces of CCA treated sections /mm penetration	
0	9·1 ± 0·6	7·4 ± 1·2	
6	12·4 ± 2·2	8·8 ± 1·3	
12	16·9 ± 2·2	8·3 ± 0·4	Corsican Pine
18	17·8 ± 2·0	7·5 ± 0·3	
24	19·8 ± 3·0	9·5 ± 0·6	
0	10·8 ± 0·2	7·4 ± 1·2	
6	15·8 ± 1·3	9·5 ± 0·3	
12	15·9 ± 1·8	9·4 ± 1·2	Scots Pine
18	22·6 ± 1·5	8·8 ± 0·5	
24	22·1 ± 2·8	9·9 ± 0·7	
0	7·4 ± 0·1	7·5 ± 0·5	
6	13·9 ± 2·1	8·9 ± 0·8	
12	16·6 ± 1·9	9·2 ± 0·2	Norway Spruce
18	21·0 ± 2·6	9·1 ± 0·4	
24	19·1 ± 3·7	9·6 ± 0·8	
0	5·9 ± 0·5	7·5 ± 1·0	
6	13·6 ± 1·5	7·9 ± 0·8	
12	10·2 ± 2·0	8·6 ± 0·8	Sitka Spruce
18	17·3 ± 1·6	8·4 ± 0·7	
24	21·9 ± 1·9	8·9 ± 1·2	

Pilodyn readings for CCA treated and untreated sections after continued soil exposure. The lower Pilodyn penetrations recorded in the unburied CCA treated pine sections compared with untreated controls indicate a surface hardening effect due to CCA treatment but no comparable effect is obvious in the spruces.

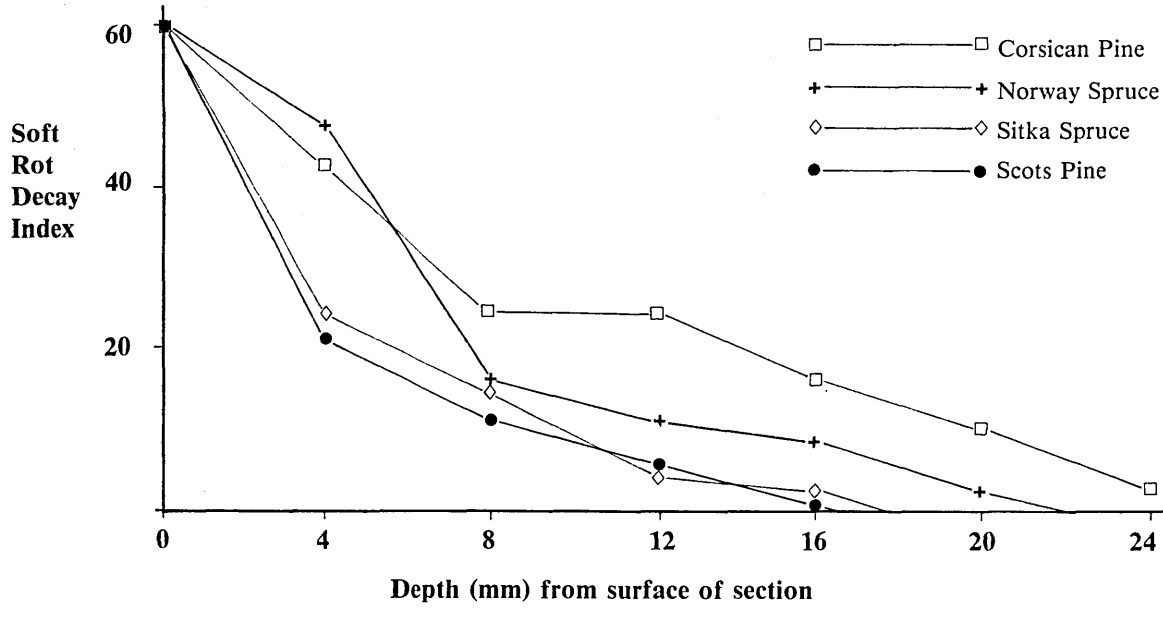

Figure 2. "Soft Rot Decay Index" showing the severity of radial soft rot penetration in sections after 12 months soil exposure.

Soft rot decay indices produced after microscopic analysis of large untreated control samples (Figure 2) also indicate satisfactory levels of decay in the soil-bed system. Extensive soft rot cavitation is present in all species with the Corsican pine sections being particularly badly affected. For this species soft rot was recorded at a depth of 12 mm after only six months burial.

In contrast to the extensive depths of soft rot decay found in the control sections of all four wood species, no soft rot attack has been identified on the exposed tangential (curved) surfaces of any of the CCA sap displaced pole sections after 24 months burial in the accelerated soil bed decay facility.

Discussion

The weight losses produced in the small lime blocks indicate that the system has a high decay potential and is operating successfully. Small lime blocks were selected for this purpose since the rate of soft rot decay in similar blocks had been established from previous studies at this Institute using standard laboratory based soil block test systems. The authors accept, however, that in larger timbers different types of organisms may well be responsible for attacking both treated and untreated hardwoods and softwoods. Internal brown rot decay was indeed found in many of the sections particularly the spruces after extended exposure periods (Hainey, 1991). After an initial period during which water was regularly and frequently added to the soil-beds to maintain them at the desired moisture content they reached a suitable state of equilibrium, with additional spraying required only infrequently (about every 8 – 10 weeks). No problems with soil or wood waterlogging or soil crusting as identified as potential problems in accelerated soil bed systems by Johnson *et al.* (1982) have been encountered during this study. Although small inter-tank variations were observed in both moisture contents and weight losses in small lime blocks after burial, in no single tank were conditions limiting to decay. Indeed the minimum mean weight loss of the four blocks in any single tank was 27% after six weeks burial.

A number of authors have examined and commented on the use of accelerated soil-bed facilities and their advantages and disadvantages (Hedley, 1980, 1983; Johnson *et al.*, 1982; Vinden *et al.*, 1983) but no direct comparison between the decay hazard in such facilities and the field can be made since little work on the microbial ecology of the former has been undertaken. While there is little doubt that wood decay rate is accelerated in the soil-bed systems compared with the field tests it is most unlikely that the microflora of soil in a soil bed system is subjected to the same fluctuating environmental pressures as that of a field test site soil. Consequently it is reasonable to expect that the wood placed in soil under such conditions may be exposed to an entirely different type of soil microflora. For this reason it is not really realistic to calculate acceleration factors for fungal cellars over field tests and it is even more speculative to extrapolate field performance from soil-bed results. The choice of the term "Accelerated field simulator" to describe a soil-bed test facility is perhaps an unfortunate one since while these test systems do supply many of the advantages associated with field testing they cannot reasonably be described as simulating all the conditions present in the field. More recently Ruddick (1989) has attempted to re-define the role of the 'fungal cellar" in the testing of wood and wood products.

It is apparent from the results (Table 2 and Figure 2) that the Pilodyn can be successfully used to monitor the soft rot decay process in untreated controls. Though the moisture content in the wood sections increased with time this did not restrict the ability of the Pilodyn to assess soft rot decay. Friis-Hansen (1980) reported that above fibre saturation point increasing moisture content had a negligible effect on Pilodyn readings. Since all pole sections in this study were wet up to approximately 30% moisture content prior to Pilodyn testing, increases in readings with time indicated soft rot decay which was confirmed by subsequent microscopic analysis.

The two CCA treated pine species showed lower surface pilodyn penetration than their untreated controls. While this may simply be due to differences in the densities of the poles used for controls or CCA treatment respectively, CCA treatment is known to cause a surface hardening of treated timber (Jonnsson *et al.*, 1989). This effect may well be associated with the increased hydrophobic character of the wood, attributed to the chromium (VI) component of the preservative (Pizzi and Conradie, 1986; Feist and Ellis, 1978). A similar effect was not recorded for the spruce species however, and indeed the unburied CCA treated Sitka spruce sections gave significantly greater Pilodyn penetration than the two control sections. This may simply be due to the well known refractory nature of this particular wood species though CCA concentrations are also significantly lower in this timber after sap-displacement compared with Corsican and Scots pine and Norway spruce (Evans *et al.*, 1987).

While it is obvious from the microscopic analysis of the wood fibres that the severity and extent of invasiveness of the soft rot is greatest in the untreated Corsican pine, this species effect was not detected using the pilodyn. Leightley (1986) found a good correlation between the amount of soft rot (measured microscopically at various depths from the surface) and Pilodyn readings in CCA treated Eucalypt distribution poles. The results of that study and those reported earlier (Friis-Hansen, 1980; Leightley, 1982) showed that a 6 Joule Pilodyn unit was found to provide the required sensitivity in detecting external pole decay. For poles made from more dense wood species however, Friis-Hansen (1980) recommended the use of a 12 Joule Pilodyn. The failure of the Pilodyn (2 Joules) to detect

differences in depth of soft rot decay in species tested in this study may therefore simply have been due to differences in the densities of the timber species tested and a lack of penetrating power associated with the use of a less powerful pilodyn.

The variability in extent of surface soft rot decay among the four untreated wood species in this study is similar to that reported by Evans *et al.* (1988) who reported large species differences in decay susceptibility (measured by weight loss) of small sapwood blocks totally buried in unsterile soil. While these differences in decay susceptibility are almost certainly due to structural and compositional differences between the four wood species, Evans *et al.* (1988) found no marked variations in the density of the sapwood of the four species which might account for the observed differences in their decay susceptibilities. Fungal colonisation and subsequent decay are influenced by the moisture content of the wood and while the moisture content of the soils in all soil-beds was maintained at a regular level, the moisture profiles of the sections of various wood species were different (Hainey, 1991). The extent to which untreated pine wood sections wet up was much greater than the two spruce species. This is probably due to anatomical differences in the timbers including the extent of pit aspiration, with spruce species being well documented as being difficult to treat and a significant difference in the extent of pit aspiration between Corsican and Scots pine sapwood has also been reported (Phillips, 1933 in Jane, 1970).

A more important factor in determining the decay susceptibility of the wood species during soil exposure may be their nitrogen contents. Oxley *et al.* (1976) showed that the nitrogen content, particularly the soluble nitrogen content, accelerated soft rot decay in pine and spruce. While nitrogen analysis of the wood species has not been undertaken here King *et al.* (1976) reported that the nitrogen content of the outer sapwood of U.K. grown Scots pine (0·11%) was significantly higher than that of U.K. grown Sitka spruce (0·07%) and Waite (1977 pers. comm.) recorded nitrogen contents in the outer sapwood of U.K. grown Corsican pine of 0·18% after drying. If similar nitrogen contents are present in the wood sections used in this current study they might largely account for the patterns of soft rot penetration reported here.

Evans *et al.* (1987) reported that Scots and Corsican pine and Norway spruce poles, sap displaced with CCA as described in this study, contained significantly greater concentrations of CCA in the treated sapwood than Sitka spruce poles. Indeed the copper concentrations in the surface layers of Sitka spruce (0.14% m/m element) were below the figure of 0.2% (m/m element) reported by Nilsson (1982) as the toxic threshold for the decay of *Pinus* spp. by soft rot organisms. Despite this, no soft rot has been detected in this study either microscopically or by pilodyn measurements within the treated regions on the tangential surfaces of Sitka spruce sections after 24 months incubation.

Internal pockets of soft rot have, however, been found in treated sections of Norway and Sitka spruce and Scots pine. These cavities have been associated with the open checks in the sections and have generally been located in the untreated heartwood regions. In a few Sitka spruce sections however, small internal pockets of soft rot were found within the treated region inside the checks after only 18 months soil exposure. CCA concentrations are much lower internally than at the pole surface due to the radial distribution pattern of the CCA salts produced during sap-displacement treatment (Evans *et al.*, 1987). Such internal soft rot has also been reported in CCA treated Telecommunication poles in Sweden after more than 20 years field service (Friis-Hansen and Lundstrom, 1989).

Since the results of this study, and those reported in Hainey (1991), indicate that internal colonisation by soft rot and basidiomycete fungi can take place through checks in treated pole sections, it is obvious that if CCA treatment by sap-displacement is to be a viable alternative to pressure treatment of poles then a good, deep, even penetration of the salt must be achieved. This is particularly important with sap-displacement since, unlike traditional pressure treatment, the poles are not dried before treatment and hence any subsequent checks which may form might expose untreated timber. In contrast, traditionally treated poles are dried prior to treatment and the surfaces of any checks which are produced may be treated with the preservative.

Conclusion

It is obvious from the results presented here that the accelerated soil-bed decay facility described can be a very useful test system for the analysis of the decay susceptibility of CCA treated distribution pole sections. The facility provides a test system which permits the use of large-dimensioned, representative timbers which is essential to any realistic study of the decay of treated distribution poles and yet still provides results within a reasonable timescale. While the test system cannot predict accurately the absolute field service life of the poles the results presented here clearly show that it provides an ideal test system for the comparative evaluation of different wood species for use as distribution poles and for testing various preservative treatments of such material.

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